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Gerri De Luca
Name (Print)

Signature

Atty. Ref. No.: 1374-004P

GENERIC TYPED DGC CLASSES FRAMEWORK

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a theoretical model or framework for representing a unification of the semantics of sequential programming languages, i.e., sequential procedural and sequential object oriented programming languages (OOPL), independent of their syntax.

Description of Related Art

Type Theory of Programming Languages has been the target of focus as the basis for unification of programming languages. Based on this Type Theory, Microsoft has developed an intermediate language called Typed Intermediate Language (TIL) for their .net framework. TIL is a stack-based assembly language and a wrapper for Intel's assembly. It is based on a stack execution model and looks alien to a high-level language programmer. The purpose of TIL is to create a common execution model capable of supporting language interoperability. It has Classes directly built in (thus support for OO) at the Assembly Level. It is desirable, however, to unify programming languages at the level of their Definition and Semantics rather than being tied to the memory execution model of any particular platform. This offers the advantage to customers of converting their applications

of any particular platform. This offers the advantage to customers of converting their applications from legacy programming languages to contemporary ones independent of the platform of execution.

The same inventors and assignee of the present invention developed an earlier or predecessor to the present inventive framework referred to as Typed DGC Classes based on: (i) the Theory of Computability; (ii) Axiomatic Semantics of Programming Languages; and (iii) Type Theory of Programming Languages. The Typed DGC Classes were designed to unify programming languages at the level of their Source Language Definition and Semantics however, this framework was only suitable for imperative procedural languages, e.g., C, Pascal and Cobol, and did not have the capability of handling Pointers, Modules, Structures, Classes, and Objects.

It is therefore desirable to develop an improved model or framework to capture the semantics of programming languages that is independent of the syntax of any programming language, independent of the execution platform, and suitable for sequential programming languages (both sequential procedural and sequential object oriented programming languages).

Summary of the Invention

All computer programming languages fall within the limits defined by the Theory of Computability developed by Turing or equivalent approaches such as Lambda Calculus, Theory of Recursive Functions, or Markov Algorithms. It is desirable to develop a unifying programming language that adheres to these central and underlying concepts.

The present invention is a system and method for universal programming language conversion using a model representing a unification of the semantics of sequential programming languages and is hereinafter referred to as Generic Typed DGC Classes Framework. Development of this Generic Typed DGC Classes Framework was based on the following mathematical principles:

- Theory of Computability as described by Martin Davis in the book entitled "*Computability and Unsolvability*", (1982).
- Axiomatic Semantics of Programming Languages as disclosed in the publications entitled "*A Discipline of Programming*" by Edsger Dijkstra (1976) and "*Formal Semantics of Programming Languages*" by Glynn Winskel (1993).

- Type Theory of Programming Languages as described in the publications entitled "*Structure of Typed Programming Languages*" by David Schmidt (1994) and "*Foundations for Programming Languages*" by John Mitchell (1996).

Every sequential program is limited by these underlying principles. Thus, unification of all sequential programming languages is possible by capturing the semantics of such languages based on these theories.

Specifically, an embodiment of the present invention is directed to a method for universal programming language conversion between two different sequential programming languages. In particular, conversion is between a source program in a first programming language and a target program in a second programming language. Initially, the source program in the first programming language is parsed using a parsing interface specific to the first programming language. All syntax from the parsed source program is then stripped or removed. Classes in a framework are instantiated to capture semantics of the parsed source program independent of syntax and execution model of the sequential programming languages. The classes are C++ classes representing fundamental core constructs of all sequential programming languages. A semantic representation of the parsed source program without any syntax is produced. The semantic representation is received at a printer interface specific to the second programming language and syntax of the target program in the second programming language is added. This process can be used for any type of language conversion, e.g., high level translation or compilation depending on whether the target programming language is high level or low level programming language, respectively.

Another embodiment of the present invention is directed to an apparatus for universal programming language conversion using the method described above. The apparatus comprises a parsing interface specific to the first programming language for parsing the source program in the first programming language and stripping all syntax from the parsed source program. Classes in a framework are instantiated to a produce a semantic representation of the parsed source program independent of syntax and execution model of the sequential programming languages. A printer interface specific to the second programming language is plugged into the back end. The printer interface receives the semantic representation and adds the syntax of the target program in the second programming language.

Still another embodiment of the invention relates to an apparatus for universal programming language conversion between two different sequential programming languages including a source program in a first programming language and a target program in a second programming language, wherein the apparatus comprises a processor for instantiating classes in a framework representing a unification of semantics of the sequential programming languages (e.g., sequential procedural and sequential object oriented programming languages) independent of syntax and execution model.

Brief Description of the Drawings

The foregoing and other features of the present invention will be more readily apparent from the following detailed description and drawings of illustrative embodiments of the invention wherein like reference numbers refer to similar elements throughout the similar views and in which:

Figure 1 is an exemplary schematic of the base **Type** (core constructs) hierarchy identified in the Generic Typed DGC Classes Framework in accordance with the present invention;

Figure 2 is an exemplary schematic of the base **Descriptor** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 3 is an exemplary schematic of the **Basic Computable Type Descriptors** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 4 is an exemplary schematic of the **Composite Type Descriptors** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 5 is an exemplary schematic of the base **Value** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 6 is an exemplary schematic of the base **Constant** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 7 is an exemplary schematic of the internal structure of ***Location*** in accordance with the Generic Typed DGC Classes Framework;

Figure 8 is an exemplary schematic of the base **Location** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 9 is an exemplary schematic of the base **Variable** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 10 is an exemplary schematic of the assignment of an **Address Value** to a **Variable** of **Type Pointer** in the Generic Typed DGC Classes Framework;

Figure 11 is an exemplary schematic of the base **Accessor** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 12 is an exemplary schematic of the base **Computable Expressions** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 13 is an exemplary schematic of the base **Left Hand Side Identifier** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 14 is an exemplary schematic of the base **Command** hierarchy identified in the Generic Typed DGC Classes Framework;

Figure 15 is an exemplary schematic diagram of language conversion (e.g., language translation and/or compilation) using the present inventive Generic Typed DGC Classes Framework in accordance with the present invention;

Figure 16 is a schematic diagram of an exemplary Retargetable Compiler architecture using the Generic Typed DGC Classes Framework in accordance with the present invention;

Figure 17 is an exemplary schematic diagram of a Generic Typed DGC Classes Framework representation of the Assembly Language being derived from the Generic Typed DGC Classes Framework representation of the Source Language;

Figure 18 is an exemplary schematic of the memory representation of ***Block*** **`unit4;`** and

Figure 19 is an exemplary schematic of the memory representation of ***Block*** **`unit4_AddProc`**.

Detailed Description of the Present Invention

The present inventive Generic Typed DGC Classes Framework generically represents the semantics of building blocks of any sequential programming language (both sequential procedural and sequential object-oriented programming languages), independent of its syntax and the execution model for the language on any chip (register-based or stack-based). A computer programming language generally comprises fundamental core

constructs (which make the language Turing-complete) and advanced constructs. An advanced construct is simply a shorthand way to express a combination of one or more fundamental core constructs thereby offering convenience and expressiveness to the programmer. Advanced constructs never add to or enhance the Turing-completeness of any such programming language. Thus, an advanced construct of any programming language can always be constructed from its fundamental core constructs. All programming languages are Turing-complete, but they differ in their syntax of offering the fundamental core constructs required for Turing-completeness. Additionally, some languages offer advanced constructs, which do not enhance the underlying semantical properties of Turing-completeness, but instead are merely composites of its fundamental core constructs.

The present inventive Generic Typed DGC Classes Framework has been developed as a minimal and simple set of C++ Classes that capture the semantics of the constructs in any sequential programming language independent of the syntax of any programming language and the execution model on any chip (e.g., stack based or register based). The Generic Typed DGC Classes Framework is therefore universal in that it is capable of being instantiated for any construct of any sequential programming language, albeit procedural or object-oriented.

The Generic Typed DGC Classes Framework is based on the same theoretical foundations expressed above with respect to its predecessor the Typed DGC Classes and further in consideration of aspects from the Theory of Objects, as written by Cardelli, Luca and Abadi, Martin, in the book under the same name published in 1996. The theories mentioned serve as the basis of universality by which the present inventive Generic Typed DGC Classes Framework may be applied to any sequential programming language. Accordingly, the present inventive Generic Typed DGC Classes Framework is an improvement in that it is suitable for use with a wider range of applications than that of its Typed DGC Classes predecessor.

Any sequential programming language can be broken down into fundamental core constructs that are hereinafter referred to as ***Types*** (denoted by bold italics with the first letter capitalized). These constructs serve as the building blocks for different constructs in different programming languages. Thus, all programming language constructs are combinations of these underlying fundamental core constructs (***Types***). For example, a program is a set of **`DECLARATIONS`** followed by a sequence of **`COMMANDS`**; an **`ASSIGNMENT`**

STATEMENT comprises a **VARIABLE** on the left hand side and an **EXPRESSION** on the right hand side; and an **ITERATION** is a repetitive execution of a sequence of **COMMANDS**. All sequential programming languages differ only with respect to the complexity of compositions of these fundamental core constructs (***Types***).

Each ***Type*** is defined in terms of its algebraic specification, i.e., as an ***Abstract Data Type (ADT)***. This algebraic specification translates into a C++ Class (corresponding to the ***Type*** under discussion) and its associated members (referring to the operations on that ***Type***) that have been already implemented as a minimal and simple set of C++ Classes which can be instantiated for any construct of any sequential programming language. Thus, the Generic Typed DGC Classes Framework is a C++ Class Library wherein the classes (***Types***) are instantiated to model the constructs of any sequential programming language.

Every computer programming language has two parts, i.e., states and commands. A variable and its associated value define the state of a system at a given point in time, while a command represents the operation on the state to query or change its associated value. In all programming languages the concept of commands and its representations remain the same, however, the concept of variables and their representation differ in different programming languages.

A ***Type*** may be broadly defined as a set of elements that share at least one common property or characteristic. Each programming language offers multiple varieties of ***Type***. Each ***Type*** has a ***TypeName*** associated with it (as denoted by all capital letters). The ***TypeName*** is a unique name or label used to identify each ***Type***. This ***TypeName*** corresponds to our intuitive notion of ***Types.***

The interrelation of ***Types*** is defined by Typing Rules associated with a particular programming language. Figure 1 is an exemplary hierarchical listing of base ***Types*** (representing hierarchies of related fundamental core constructs) of the present inventive Generic Typed DGC Classes Framework applicable for any sequential programming language. These base ***Types*** include: ***Descriptor***, ***Value***, ***Constant***, ***Variable***, ***Accessor***, ***Computable Expression***, ***Command***, ***Left Hand Side Identification (LhsId)***, ***Location*** and ***Environment***. Two of these identified base ***Types*** (i.e., ***LhsId*** and ***Location***) will only be instantiated for particular programming languages. Specifically, ***LhsId*** will only be instantiated for imperative, not functional, programming languages, whereas ***Location*** need only be instantiated for those particular programming languages that employ pointers. The

remaining base ***Types*** (***Descriptor***, ***Value***, ***Constant***, ***Variable***, ***Accessor***, ***Computabl Expressi n***, ***Command*** and ***Environment***) will be instantiated for every programming language.

Of these base ***Types***, ***D scriptor*** and ***Environment*** are special categories. ***Descriptor*** is used to specify (describe) properties of certain other ***Types*** and is used as the basis from which these other ***Types*** are constructed. ***Environment*** is used for creating and storing other ***Types*** (including instances of ***Descriptor*** and ***Environment***), that is, ***Environment*** is the container for all ***Types***. The ***Environment*** recognizes the ***Types*** and associated Typing Rules supported by the particular programming language.

An ***Environment*** comprises the Language Context (which defines the programming language based on its recognized ***Types*** and associated Typing Rules supported by the particular programming language), and the Program State (i.e., the set of ***Variables*** and their associated ***Values*** declared for a given program). Thus, the ***Environment*** is the substrate ***Type*** on which a programming language is defined, constructed, and executed.

Data Types may also be classified as a ***Basic Computable Type*** or a ***Composite Type*** specified (described) by their corresponding ***Descriptors*** and the ***Environment*** that recognizes or supports them. The term ***Basic Computable Type*** is defined as those ***Types*** which (i) are not composed from any other ***Type*** and (ii) for whom direct computations are possible on their ***Values***.

Some exemplary ***Basic Computable Types*** (with their associated conventional TYPENAME identified within [] brackets in all capital letters) include:

- ***Integer*** [INT] (e.g., -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5)
- ***Real*** [REAL] (e.g., -2.0, -1.3, -0.6, 0, 0.7, 1.0, 1.5, 2.3)
- ***Boolean*** [BOOL] (e.g., true, false)
- ***Character*** [CHAR] (e.g., ‘ ‘, a, b, c, d, 1, 2, @, #, ‘, ….. .)
- In some programming languages ***Basic Computable Types*** also include
  String [STRING] (e.g., “city”, “Boston”, “Paul”, “123”, “101bDH#*^&”)
- ***Void*** [VOID] (null value)

String has been identified as a ***Basic Computable Type*** in the present inventive Generic Typed DGC Classes Framework, for matters of practical convenience. However, the present inventive framework could be modified so that only ***Character*** is classified as a

Basic Computable Typ , while ***String*** is a ***Composite Typ*** as constructed from ***Character***.

The **TYPENAME** associated with each ***Type*** may be selected, as desired, without having any impact on the invention. In the present inventive framework, the ***Types*** of **INT**, **REAL**, **STRING** and **CHAR** have each been assigned a unique Type Name. It is, however, recognized, for example, that **ARITHMETIC** may be the Type Name used to generically refer to either ***Integer*** or ***Real***, while **STRING** may be used to refer to either ***Character*** or ***String***.

Composite Types represent compositions of one or more ***Basic Computable Types*** and/or ***Composite Types***. Some exemplary ***Composite Types*** may include:

- ***Pointer***, which "points to" or "refers to" an element of any ***Type*** or a ***Type*** that has not yet been specified;
- ***Array***, which represents a finite and indexed set of elements of the same ***Type***; and
- ***Record***, which represents a finite set of elements that may belong to different ***Types***.

As noted above, each kind of ***Basic Computable Type*** and ***Composite Type*** is instantiated only through the different kinds of ***Variables*** by specifying their corresponding ***Descriptors*** and associated ***Environment*** that supports or recognizes these ***Types***, as described further below.

The present inventive Generic Typed DGC Classes Framework is explained by first describing the ***Types*** and associated Typing Rules and thereafter defining their interconnection within the ***Environment***.

Each ***Type*** is axiomatized based on an algebraic specification (an ***Abstract Data Type*** (***ADT***)) as prescribed by Meyer, Bertrand, in the publication entitled "*Object-Oriented Software Construction*", (1977)(2nd Ed.), which in turn is based on the theory of Many-Sorted Algebras. This algebraic specification comprises a **Signature** representing the set ***{S, Ω}***, where ***S*** represents the ***Sort*** (***Type***) under construction and ***Ω*** is its associated set of operators. This specification directly translates into a Class (i.e., ***Type***) and its associated members (i.e., operations on that ***Type***). Three distinct categories of **Operators** are defined viz: **Creators**, **Modifiers**, and **Queries**. **Creators** create ***Types***, **Modifiers** modify or change ***Types***, while **Queries** return information about ***Types*** (without changing them). **Properties** associated with each ***Type*** are represented as **Axioms** and **Preconditions**. **Axioms** describe properties to be adhered to for any instance of a particular ***Type*** that is the

target or subject of any operator; while **Preconditions** represent the properties to be satisfied for any instance of a particular ***Typ*** prior to being the target of any **Operator**.

Instantiation of this algebraic specification for a fundamental or base ***Abstract Data Type (ADT)*** generic to all ***Types*** is represented as follows:

ADT for base Type

S = {Type}

Ω = {

Creators: None

Modifiers: None

Queries:

GetTypeName:	***Type → TypeName***
GetInnerTypeName:	***Type → TypeName***
Print:	***Type → String***

}

Axioms:

{

None

}

Preconditions:

{

None

}

In the generic algebraic specification for base ***Type*** above, no **Creator** is specified. Instead, the **Creator** for each kind of ***Type*** will be specified in its corresponding algebraic specification. Each kind of ***Type*** always has at least two associated Type Names, which are built-into each instance at the time of their creation into the ***Environment***. Some ***Types*** may have more than two **TYPENAMEs**. One of these **TYPENAMEs** referred to as "**TypeNam** "

represents that name of the particular ***Type*** (e.g., ***Descriptor***, ***Variabl*** or ***Command***), whereas the other Type Name referred to as "`InnerTypeNam`" represents the kind of the particular ***Type***, that is, the kind of ***Basic Computable Type*** (e.g., ***Integer***, ***Boolean***, ***Real***, ***Character***, ***Address***, ***String***, ***Void***) or the kind of ***Composite Type*** (e.g., ***Array***, ***Record***, ***Pointer***, ***Function***).

This ADT for base ***Type*** represents the parent or base ***Sort (Type)*** from which all other ***Types*** are derived. In accordance with accepted inheritance principles associated with object oriented programming languages, a more enhanced or specific derived ***Sort (Type)*** may be created from this more generic parent or base ***Sort (Type)***. All derived ***Sort (Type)*** will always inherit all **Operators** and **Properties** (e.g., **Axioms** and **Preconditions**) associated with the parent or base ***Sort (Type)***. These inherited **Operators** and their associated **Properties** cannot be eliminated but may be appended or enhanced with additional **Operators**, additional **Properties**, inherited **Operators** **and/or inherited** **Properties** may be strengthened (e.g., via additional **Operators** and/or **Properties**). For ease of convenience in the descriptions provided below the **Operators** associated with the base ***Sort (Type)*** will not necessarily be restated with respect to the particular ADT for a specific kind of derived ***Sort (Type)***. Nevertheless, based on the well-established principle of inheritance associated with conventional object oriented programming languages, all **Operators** and associated **Properties** associated with the parent or base ***Sort (Type)*** will implicitly be included in the derived ***Sort (Type)***, regardless of whether they are explicitly mentioned in their respective ADTs.

Creators for all ***Types*** (as specified in their respective ADTs described fully below) are actually targeted on the ***Environment***, such that each **Creator** has ***Environment*** as an argument (which is not explicitly mentioned in the ADTs described further below). However, the properties of ***Data Types*** (i.e., ***Basic Computable Types*** and ***Composite Types***) are captured in appropriate ***Descriptors***, hence these ***Descriptors*** are used to instantiate ***Types***.

For each of the ***Basic Computable Types*** and ***Composite Types*** an appropriate ***Descriptor*** specifies its properties. Instantiation of a specific kind of ***Type*** is realized using **Creator** for ***Variable*** with respect to each particular ***Basic Computable Type*** or ***Composit Typ***. Some exemplary instantiation **Creators** for ***Variables*** include:

- "give me a ***Variabl*** of ***X***", where ***X*** is any ***Basic Computable Type***;

- "give me a ***Variable*** of ***Pointer*** with Inn rTypeName ***X***";
- "give me a ***Variable*** of ***Array*** of ***X*** with ***n*** dimensions and $k_1 \dots k_n$ as bounds of these ***n*** dimensions";
- "give me a ***Variable*** of ***Record*** of ***Types*** $t_1 \dots t_k$."

A ***Variable*** needs an instantiation of a ***Data Type*** (i.e., ***Basic Computable Type*** or a ***Composite Type***). A ***Type***, however, cannot be instantiated within the ***Environment*** and then be given to any ***Variable*** asking for it – as that implies having an "orphan" ***Type*** (i.e., a ***Type*** that is instantiated but not associated with any ***Variable***) in the ***Environment.*** Hence, the instantiation of ***Type*** needs to be done from within the Creator for ***Variable***.

In order to instantiate a specific kind of ***Data Type***, its complete algebraic specification in the form of a ***Descriptor*** is passed to the Creator for ***Variable***. Initially, an appropriate ***Descriptor*** is obtained from ***Environment*** in which the ***Variable*** is to be created. This ***Descriptor*** may initially be plain (i.e., without any specific content) – e.g., for a ***Record Variable***, a ***Record Descriptor*** without any elements). Construction of the ***Descriptor*** is completed by using the corresponding defined Operators. Once a ***Variable*** has been instantiated by using a ***Descriptor***, thereafter the associated properties of the ***Descriptor*** are prevented from being altered.

Descriptors may either be referred to by a Name represented by ***String*** that is queried by "***GetName***" on the ***Descriptor*** or alternatively no name may be assigned whereby the ***String*** is empty. Thus, two Creators exist for each ***Descriptor*** – one with a Name, and the other without a Name. Naming the ***Descriptor*** is advantageous in that it allows User-defined Data Types (UDT) and Inheritance from other Named ***Descriptors.*** For the purposes of describing the present inventive framework, the possibility of Inheritance from ***Descriptors*** has been limited to ***Record*** only. However, it is contemplated and within the intended scope of the present invention to alternatively, or in addition thereto, extend Inheritance to other ***Descriptors***.

Figure 2 is a hierarchy of the base ***Descriptor*** {***Desc***} and its derived species (e.g., ***Basic Computable Type Descriptor*** {***BasicCompTypeDesc***}, ***Array Descriptor*** {***ArrayDesc***}, ***Function Descriptor*** {***FunctionDesc***}, ***Pointer Descriptor*** {***P interDesc***}, and ***Record Descriptor*** {***R cordDesc***}).

The ADT for base ***Descriptor*** is provided below:

Base ADT for Descriptor

S = {Desc}

Ω = {

Creators: None

- Once again no **Creator** is specified in the ADT for the base ***Descriptor***, instead the ADT associated with each kind, species or derived ***Descriptor*** will have its own specified **Creator**.
- Once a ***Descriptor*** has been instantiated (e.g., by a ***Variable***), thereafter the properties associated therewith cannot be changed.

Modifiers:

IncrInUseCount:	***Desc → Desc***
DecrInUseCount:	***Desc → Desc***

- ***Increase In Use Count*** {***IncrInUseCount***} represents the number of ***Variables*** that has instantiated the ***Descriptor.***
- After successful creation of the ***Variable, IncrInUseCount*** is invoked by the **Creator** of any kind of ***Variable*** (on its input ***Descriptor***) to increment the value by one.
- The ***Decrease In Use Count*** {***DecrInUseCount***} is invoked to decrease the value by one when the ***Variable*** is deleted from the ***Environment***.

Queries:

IsEqual:	***Desc × Desc → Bool***
GetName:	***Desc → String***
GetTypeName:	***Desc → TypeName***
GetInnerTypeName:	***Desc → TypeName***
Print:	***Desc → String***
GetInUseCount:	***Desc → Int***

- The total number of ***Variables*** that has instantiated the ***Descriptor*** is represented by ***InUseCount***.

}

<u>Axioms:</u>

{

Let ***d*** be an instance of any kind of ***Desc***.

Let ***n*** be an instance of ***Int***.

GetTypeName (d) = DESCRIPTOR

GetInUseCount (d) = n ***IMPLIES***

GetInUseCount (IncrInUseCount (d)) = n + 1

Let ***d1*** be an instance of any kind of ***Desc*** (without a ***Name***).

IsEmpty (GetName (d1)) = T

Let ***d2*** be an instance of any kind of ***Desc*** (with a ***Name***).

IsEmpty (GetName (d2)) = F

Let ***d3*** and ***d4*** be instances of any ***Desc***.

IsEqual (d3, d4) This Equality <u>**Axiom**</u> is equivalent to the following equivalence conditions being satisfied:

(

GetTypeName (d3) = DESCRIPTOR = ***GetTypeName (d4)***;

AND

GetInnerTypeName (d3) = GetInnerTypeName (d4)

)

- The Equality <u>**Axiom**</u> is true, i.e., ***d3*** and ***d4*** are the same ***Descriptors*** if two conditions are met – (i) both ***Descriptors*** have the same Type Name (i.e., DESCRIPTOR), and (ii) their Inner Type Name is the same for both.
- This Equality <u>**Axiom**</u> is generic to the base ***Descriptor*** and may be further enhanced with additional equivalence conditions for each particular kind of ***Descriptor***.
- Thus, the default Equality <u>**Axiom**</u> for any ***Descriptor***, as provided above, requires equivalence of the corresponding elements of the two structures

or records. (It is noted that for ***Descriptor*** of ***Record***, equivalence of ***Nam*** is also required, as described further below.)

}

Preconditions:

{

Let ***d1***, ***d2*** be instances of ***Descriptor***.

For creating any ***Descriptor*** with a ***Name***, the ***Name*** should not:

- already exist in the ***Environment*** in which the ***Descriptor*** is being created, i.e., the **Query** on the ***Environment*** should return ***FALSE***; and
- be empty, i.e., the **Query** ***IsEmpty (Name)*** should return ***FALSE***.

All **Modifiers** except ***IncrInUseCount()*** and ***DecrInUseCount()*** (for any ***Descriptor***) require that the query ***GetInUseCount (Desc) = 0***.

}

Now the ADT for each kind of ***Descriptor*** (e.g., ***Basic Computable Type Descriptor***, ***Array Descriptor***, ***Function Descriptor***, ***Pointer Descriptor*** and ***Record Descriptor***) identified in Figure 2 will be specified. Once again it is noted that each kind of ***Descriptor*** need not necessarily be instantiated depending on the programming language. For example, ***Array Descriptor***, ***Function Descriptor***, ***Pointer Descriptor*** and ***Record Descriptor*** need only be instantiated for those programming languages that recognize these elements. Each kind of ***Descriptor*** is derived from the ADT for base ***Descriptor***, as described above, and therefore inherits all specified properties associated therewith.

The following base or generic ***Descriptor*** is provided for all ***Basic Computable Types***:

ADT for Basic Computable Types Descriptor

S = {BasicCompTypeDesc}

Ω = {

Creators:

BasicCompTypeDesc: ***TypeName*** $\hookrightarrow$ ***BasicC mpTypeDesc***

NamedBasicCompTypeDesc: ***String*** $\times$ ***TypeName*** $\hookrightarrow$ ***BasicCompTypeDesc***

- The symbol $\hookrightarrow$ used in these **Creators** and other ADTs below represent a partial function.

Modifiers: None

Queries:

GetCompTypeName: ***Desc*** $\rightarrow$ ***TypeName***

}

Axioms:

{

Let ***t*** be a **TypeName** such that

t $\in$ { **BOOL, INT, REAL, CHAR, STRING, ADDRESS, VOID** }

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let ***s*** be an instance of ***String***.

GetInnerTypeName (d) = **BASICCOMPTYPE**

GetCompTypeName (BasicCompTypeDesc (t)) = t

GetInUseCount (BasicCompTypeDesc (t)) = 0

GetCompTypeName (NamedBasicCompTypeDesc (s, t)) = t

GetInUseCount (NamedBasicCompTypeDesc (s, t)) = 0

- ***BasicCompTypeDesc*** represents the ***Basic Computable Type Descriptor*** without a Name assigned thereto.
- ***NamedBasicCompTypeDesc*** represents the ***Basic Computable Type Descriptor*** with a Name assigned thereto represented by an instance ***s*** of ***String***.

Let ***d1***, ***d2*** be instances of ***BasicCompTypeDesc***.

IsEqual (d1, d2) This Equality **Axiom** is equivalent to the following equivalence conditions being satisfied:

(

GetTypeName (d1) = GetTypeName (d2); AND

GetInnerTypeName (d1) = GetInnerTypeName (d2); AND

GetCompTypeName (d1) = GetCompTypeName (d2)

)

- This last equivalence condition in the above-given Equality **Axiom** has been specified for the kind ***BasicCompTypeDesc*** in addition to those inherited base conditions specified for the ADT for base ***Descriptor***.

}

Preconditions:

{

Let ***s*** be an instance of ***String***.

Let ***t*** be a ***TypeName***.

BasicCompTypeDesc (t)

NamedBasicCompTypeDesc (s, t)

Both require that ***t*** be a ***Basic Computable Type***:

t ∈ { **BOOL, INT, REAL, CHAR, STRING, ADDRESS, VOID** }

}

Additional properties may be specified for each kind of ***BasicCompTypeDesc*** for TypeName ***t***, where ***t*** ∈ {**BOOL, INT, REAL, CHAR, STRING, ADDRESS, VOID**}. Instantiations of ***BasicCompTypeDesc*** are precisely the corresponding ***Basic Computable Types***, as shown in Figure 3. Each kind of ***BasicCompTypeDesc*** has its own associated **Operators** that need not been the same. For practical purposes only those **Operators** necessary for axiomatizing certain ***Types*** have been identified in describing the present inventive framework. Theoretically, any **Operators** that are available at the implementation

level for all programming languages but have not been described in the present application can be invoked as and when required.

The properties associated with each kind of ***BasicCompTypeDesc*** for TypeName ***t***, where ***t*** $\in$ {`BOOL`, `INT`, `REAL`, `CHAR`, `STRING`, `ADDRESS`, `VOID`} will now be addressed.

<u>ADT for the Basic Computable Type Descriptor - Boolean</u>

S = {Bool}

Ω = {

<u>Creators:</u> None

<u>Modifiers:</u> None

<u>Queries:</u>

And:	***Bool*** $\times$ ***Bool*** → ***Bool***
Or:	***Bool*** $\times$ ***Bool*** → ***Bool***
XOr:	***Bool*** $\times$ ***Bool*** → ***Bool***
Not:	***Bool*** → ***Bool***
EqualBool:	***Bool*** $\times$ ***Bool*** → ***Bool***
LessThanBool:	***Bool*** $\times$ ***Bool*** → ***Bool***
GetCompTypeName:	***Bool*** → ***TypeName***

}

<u>Axioms:</u>

{

Let ***b*** be an instance of ***Bool***.

- ***Bool*** can take only the symbolic values ***T*** or ***F*** (which are representations of our intuitive Boolean notions of ***TRUE*** and ***FALSE***, respectively).

And (b, Not (b)) = F

Or (b, Not (b)) = T

And (b, F) = F

Or (b, T) = T

Not (T) = F

Not (F) = T

XOr (b, Not (b)) = T

GetCompTypeName (b) = BOOL

}

Preconditions:

{

None

}

ADT for the Basic Computable Type Descriptor - Integer

S = ***{Int}***

Ω = {

Creators: None

Modifiers: None

Queries:

Add: ***Int × Int → Int***

Subtract: ***Int × Int → Int***

Multiply: ***Int × Int → Int***

IntDiv: ***Int × Int ↬ Int***

- ***IntDiv*** is a partial function (denoted by ↬) because the divisor (second ***Int***) cannot be zero.

EqualInt : ***Int × Int → Bool***

LessThanInt: ***Int × Int → Bool***

GetCompTypeName: ***Int → TypeName***

}

Axioms:

{

Let ***n*** be an instance of ***Int***.

Add (n, 0) = n
Multiply (n, 1) = n
Multiply (n, 0) = 0

GetCompTypeName (n) = INT

}

Preconditions:

{

Let ***n1***, ***n2*** be instances of ***Int***.

IntDiv (n1, n2)
Requires: ***n2*** $\neq$ ***0***.

}

ADT for the Basic Computable Type Descriptor - Real

S = {Real}

Ω = {

Creators: None
Modifiers: None
Queries:

Add: ***R al*** $\times$ ***Real*** → ***Real***

Subtract: ***Real*** $\times$ ***Real*** → ***Real***

Multiply: ***Real*** $\times$ ***Real*** → ***Real***

Div: ***Real*** $\times$ ***Real*** ↪ ***Real***

- ***Div*** is a partial function (denoted by ↪) because the divisor (2nd ***Real***) cannot be zero.

EqualReal: ***Real*** $\times$ ***Real*** → ***Bool***

LessThanReal: ***Real*** $\times$ ***Real*** → ***Bool***

GetCompTypeName: ***Real*** → ***TypeName***

}

<u>Axioms:</u>

{

Let ***r*** be an instance of ***Int*** or ***Real***.

- ***r*** is an instance of ***Int*** implies that ***r*** is an instance of ***Real*** since ***Int*** is a species or subset of ***Real***.

Add (r, 0) = r

Multiply (r, 1) = r

Multiply (r, 0) = 0

GetCompTypeName (r) = REAL

}

<u>Preconditions:</u>

{

Let ***r1***, ***r2*** be instances of ***Int*** or ***Real***.

Div (r1, r2)

Requires: ***r2*** $\neq$ ***0***

}

ADT for the Basic Computable Type Descriptor - Character

S = {Char}

Ω = {

Creators: None

Modifiers: None

Queries:

Pred:	***Char ↪ Char***	(Predecessor function)
Succ:	***Char ↪ Char***	(Successor function)

- **Predecessor** {***Pred***} and **Successor** {***Succ***} are the ways in which a collating sequence is introduced for ordering each instance of ***Char***.

EqualChar:	***Char × Char → Bool***
LessThanChar:	***Char × Char → Bool***

GetCompTypeName: ***Char → TypeName***

}

Axioms:

{

Let ***c*** be an instance of ***Char***.

LessThan (Pred (c), c) = T

LessThan (c, Succ (c)) = T

Pred (Succ (c)) = c

GetCompTypeName (c) = CHAR

}

Preconditions:

{

Where c_{min}, c_{max} are special instances of ***Char*** such that:

For all instances ***c*** of ***Char***, $c_{min} \leq c \leq c_{max}$

Pred (c)

Requires: $c \neq c_{min}$

Succ (c)

Requires: $c \neq c_{max}$

}

ADT for the Basic Computable Type Descriptor - String

A ***String*** need not be considered a ***Basic Computable Type*** in that it can easily be constructed from ***Char***. That is, an instance of ***Char*** can also be viewed as an instance of ***String*** (of a single character). Nevertheless, for convenience a separate algebraic specification and associated **Creator** is preferably specified for ***String*** to justify its construction and the rules to be applied to concatenation and substring operations on ***Strings***.

S = {String}

Ω = {

Creators:

String: $\phi \rightarrow$ ***String***

Modifiers: None

Queries:

Concat: ***String*** $\times$ ***String*** $\rightarrow$ ***String***

- Multiple ***Strings*** may be ***Concatenated*** {***Concat***} together.

Substr : ***String*** $\times$ ***Int*** $\times$ ***Int*** $\hookrightarrow$ ***String***

- ***Substring*** {***Substr***} comprising less than all the characters may be retrieved from within the ***String***.
- Two parameters are used to identify the ***Substring***, i.e., the first ***Int*** representing the position (ordinal) within ***String*** and the second representing the length (cardinal) of the ***String***.

Length:	***String*** $\rightarrow$ ***Int***
IsEmpty:	***String*** $\rightarrow$ ***Bool***
EqualString:	***String*** $\times$ ***String*** $\rightarrow$ ***Bool***
LessThanString:	***String*** $\times$ ***String*** $\rightarrow$ ***Bool***
GetCompTypeName:	***String*** $\rightarrow$ ***TypeName***

}

<u>Axioms:</u>

{

Let ***s***, ***s1***, ***s2*** be instances of ***String***.

Let ***n*** be an instance of ***Int*** and ***c*** be an instance of ***Char***.

GetCompTypeName (s) = STRING

Length (String ()) = 0

IsEmpty (s) This <u>Axiom</u> is equivalent to the following condition being satisfied: ***(Length (s) = 0)***;

Length (Concat s1, s2) = Add (Length (s1), Length (s2));

Substr (Concat (s1, s2), 1, Length (s1)) = s1;

Substr (Concat (s1, s2), Length (s1) + 1, Length (s2)) = s2;

Concat (Substr (s, 1, n), Substr (s, n + 1, Length (s))) = s;

The next four <u>Axioms</u> are for an instance of ***Char*** (viewed as ***String***).

IsEmpty (c) = F

Length (c) = 1

Substr (c, 1, 1) = c

Length (C ncat (s, c)) = Length (s) + 1

}

Preconditions:

{

Let ***s*** be an instance of ***String***, and ***nPos, nLen*** are instances of ***Int***.

Substr (s, nPos, nLen)

Requires the following conditions be satisfied:

Not (IsEmpty (s)); AND

0 < nPos ≤ Length (s); AND

0 < nPos + nLen ≤ Length (s)

}

ADT for the Basic Computable Type Descriptor - Address

Address may not be supported by some programming languages as a usable concept by programmers. Nevertheless, ***Address*** is classified as a ***Basic Computable Type*** in the present inventive Generic Typed DGC Classes Framework. The reasoning behind classifying ***Address*** in the present inventive framework as a ***Basic Computable Type*** is that it maps onto the concept of Memory Address in the Virtual (or Real) Address Space, however primitive, that is provided by all Operating Systems.

S = {Address}

Ω = {

Creators:	None
Modifiers:	None
Queries:	
EqualAddress:	***Address × Address → Bool***
GetCompTypeName:	***Address → TypeName***
Previous:	***Address → Address***
Next:	***Address → Address***

- The last two queries are for operations of ***Address*** arithmetic.

}

Axioms:

{

Let ***a*** be an instance of ***Address***.

GetCompTypeName (a) = ADDRESS

Previous (Next (a)) = a

}

Preconditions:

{

None

}

ADT for the Basic Computable Type Descriptor - Void

Like ***Address***, ***Void*** is also classified in the present inventive framework as a ***Basic Computable Type*** despite the fact that it is supported explicitly only by a few programming languages. The reason for ***Void*** being classified, as a ***Basic Computable Type***, is that it allows us to:

- Cater to flexibility of Typing Rules (as found in Dynamically Typed or UnTyped Programming Languages, for example, PureLisp); and
- Cater to uninitialized ***Variables*** (i.e., undefined ***Values***) in Typed Programming Languages.

S = {Void}

Ω = {

Creators: None

Modifiers: None

__Queries:__

EqualVoid:	***Void × Void → Bool***
GetCompTyp Name:	***Void → TypeName***

}

__Axioms:__

{

Let ***v, v1, v2*** be instances of ***Void***.

GetCompTypeName (v) = VOID

EqualVoid (v1, v2) = F

- ***Void*** simply means undefined – hence, the __Query__ ***IsEqual*** is meaningless but must be formalized. This __Axiom__ has been selected as the closest representation of such expression.

}

__Preconditions:__

{

None

}

Next the properties associated with each of the ***Descriptors*** for the ***Composite Types***, i.e., ***Pointer*** {***PointerDesc***}, ***Array*** {***ArrayDesc***}, ***Record*** {***RecordDesc***}, ***Function*** {***FunctionDesc***}, will be addressed, as shown in Figure 4. Since instantiations of ***Descriptors*** for ***Composite Types*** are precisely the corresponding ***Composite Types***, the properties associated therewith are known to the ***Environment***.

__*ADT for the Descriptor for Pointer*__

A ***Pointer*** is a ***Composite Type*** that "points to" or "refers to" an element of any ***Type***. The ***Descriptor*** for ***Pointer*** {***PointerDesc***} is specified by the following properties:

S = {PointerDesc}

$\Omega =$ {

Creators:

PointerDesc:	***Desc → PointerDesc***
NamedPointerDesc:	***Desc × String ↪ PointerDesc***

- ***Desc*** represents the ***Descriptor*** for the ***Type*** being "pointed to", while ***PointerDesc*** represents the ***Descriptor*** for ***Pointer***.

Modifiers: None

Queries:

GetPointedToTypeDesc:	***PointerDesc → Desc***
GetPointedToTypeName:	***PointerDesc → TypeName***
GetCompTypeName:	***PointerDesc → TypeName***

}

Axioms:

{

Let ***p*** be an instance of ***PointerDesc***. **Let *d*** be an instance of ***Desc***. Let ***s*** be an instance of ***String***.

GetInnerTypeName (p) = POINTER

GetCompTypeName (p) = ADDRESS

At the time of creation, a ***Pointer Descriptor*** has "pointed-to" ***Type*** set to the ***Descriptor*** that is passed as its parameter. This is reflected by the following four Axioms.

GetPointedToTypeName (PointerDesc (d)) = GetInnerTypeName (d)

GetPointedToTypeName (NamedPointerDesc (d, s)) = GetInnerTypeName (d)

GetPointedToTypeDesc (PointerDesc (d)) = d

GetPointedToTypeDesc (N medPointerDesc (d, s)) = d

GetInUseC unt (PointerDesc (d)) = 0

G tInUseC unt (NamedP interDesc (d, s)) = 0

- ***InUseC unt*** of the inner (pointed to) ***Type Descriptor*** is incremented on creation of the ***PointerDesc***.

Let ***p1*** and ***p2*** be instances of ***PointerDesc***.

IsEqual (p1, p2) This Equality <u>**Axiom**</u> is equivalent to the following conditions being satisfied:

(

GetTypeName (p1) = DESCRIPTOR = ***GetTypeName (p2)***

AND

GetInnerTypeName (p1) = POINTER = ***GetInnerTypeName (p2)***

AND

IsEqual (GetPointedToTypeDesc (p1),

GetPointedToTypeDesc (p2)) = T

)

}

<u>**Preconditions:**</u>

{

None

}

<u>***ADT for the Descriptor for Array***</u>

An ***Array*** is described by a combination of all of the following properties and the invariant relations between them:

- a ***Type Descriptor*** for the "arrayed" ***Type***;
- an ***Integer*** for maximum number of ***Dimensions (MaxDim)***, ***MaxDim*** $\geq$ ***1***.
- a ***SizeList*** representing the bounds for each ***Dimension***. Each element of the ***SizeList*** is an integer (***Int***), which represents the ***Size*** (bound) for each ***Dimension*** (***Dim***). For each (***Dim***): ***Size*** $\geq$ ***1***;
- <u>*Note:*</u> ***SizeList*** is a standard List of ***Int*** and thus need not be axiomatized further;

- an ***Int*** for the bound (***Size***) on each dimension (***Dim***). For each (***Dim***)***: Size*** $\geq$ ***1***; and the ***Array*** has the total number of ***Elements*** of the "arrayed" ***Typ*** given by the formula:

$$\Pi\ (\mathit{Size}\ (d)) \qquad \text{(For all } \mathit{Dim}\ d \text{ such that } 1 \leq d \leq \mathit{MaxDim}\text{)}.$$

The properties for the ***Descriptor*** for ***Array*** are as follows:

S = ***{ArrayDesc}***

Ω = {

Creators:

ArrayDesc:	***Desc*** $\times$ ***Int*** $\times$ ***SizeList*** ↪ ***ArrayDesc***
NamedArrayDesc:	***String*** $\times$ ***Desc*** $\times$ ***Int*** $\times$ ***SizeList*** ↪ ***ArrayDesc***

Modifiers: None

Queries:

GetArrayedTypeDesc:	***ArrayDesc*** → ***Desc***
GetArrayedTypeName	***ArrayDesc*** → ***TypeName***
GetMaxDimension:	***ArrayDesc*** → ***MaxDim***
GetSizeForDimension:	***ArrayDesc*** $\times$ ***Dim*** ↪ ***Size***

- ***MaxDim*** is an ***Int*** representing the maximum of ***Dimensions*** of the ***Array***.
- ***Dim*** is an ***Int*** representing the ***Dimension*** in question, i.e., the ***Dimension*** whose ***Size*** is required.
- ***Size*** is an ***Int*** representing the size of the ***Dimension*** in question.

GetEnvironment: ***ArrayDesc*** → ***Environment***

- For any ***ArrayDesc*** – an ***Environment*** is created within it but is not mentioned explicitly. This ***Environment*** contains the element ***Variables*** of the ***Array***. This is consistent with the description of the ADT of ***Environment***, described further below.

}

<u>**Axioms:**</u>

{

Let ***a*** be an instance of ***ArrayDesc.***

Let ***d*** be an instance of ***Desc.***

Let ***k, m, n*** be instances of ***Int*** for ***Dim, MaxDim*** and ***Size,*** respectively.

Let ***s*** be an instance of ***String.***

Let ***L*** be an instance of ***List*** of ***m Sizes*** S_1 to S_m indexed by ***k.***

GetInnerTypeName (a) = ARRAY

GetInUseCount (ArrayDesc (d, m, L)) = 0

GetInUseCount (NamedArrayDesc (s, d, m, L)) = 0

InUseCount of the inner (arrayed) ***Type Descriptor*** is incremented after creation of the ***ArrayDesc.***

GetMaxDimension (ArrayDesc (d, m, L)) = m

GetMaxDimension (NamedArrayDesc (s, d, m, L)) = m

GetSizeForDimension (ArrayDesc (d, m, L), k) = L_k

GetSizeForDimension (NamedArrayDesc (s, d, m, L), k) = L_k

GetArrayedTypeDesc (ArrayDesc (d, m, L)) = d

GetArrayedTypeDesc (NamedArrayDesc (s, d, m, L)) = d

GetArrayedTypeName (ArrayDesc (d, m, L)) = GetInnerTypeName (d)

GetArrayedTypeName (NamedArrayDesc (s, d, m, L)) = GetInnerTypeName (d)

- The previous four <u>Axioms</u> are consistent because they will eventually lead to the leaf arrayed elements of the ***Array*** (in the case of compositions of ***Array*** of ***Array*** of ...) which have to be of a ***Basic Computable Type.***

For example, if one has complex, nested data such as an ***Array*** of an ***Array*** of ***Integers***, then these ***Integers*** (which are of **Basic Computable Type**) are the leaves of this structure. The previous four <u>**Axioms**</u> guarantee that there is always a way to access each of these ***Integers*** in a consistent manner.

Let ***a1*** and ***a2*** be instances of ***ArrayDesc***.

IsEqual (a1, a2) This Equality <u>**Axiom**</u> is equivalent to the following conditions being satisfied:

(

GetTypeName (a1) = DESCRIPTOR = ***GetTypeName (a2);***

AND

GetInnerTypeName (a1) = ARRAY = ***GetInnerTypeName (a2);***

AND

IsEqual(GetArrayedTypeDesc(a1),GetArrayedTypeDesc(a2)) = T;

AND

GetMaxDimension (a1) = GetMaxDimension (a2);

AND

GetSizeForDimension (a1, k) = GetSizeForDimension (a2, k)

[For all $1 \le k \le$ ***GetMaxDimension (a1)***]

)

}

<u>**Preconditions:**</u>

{

Let ***a*** be an instance of ***ArrayDesc***.

Let ***d*** be an instance of ***Desc***.

Let ***k*** be an instance of ***Int*** for ***Dim***.

Let ***L*** be an instance of ***List*** of ***m Integers*** (representing size) L_1 to L_m indexed by ***k***.

ArrayDesc (d, m, L)

NamedArrayDesc (s, d, m, L)

- The previous two preconditions require the following conditions be satisfied:

$$1 \le m; \quad AND$$

$$1 \le L_k, \text{ for } k = 1 \text{ to } m$$

NamedArrayDesc (s, d, m, L)

Requires: ***IsEmpty(s) = F***

GetSizeForDimension (a, k)

Requires: ***1 ≤ k ≤ GetMaxDimension (a)***

}

ADT for the Descriptor for Record

A ***Record*** is defined as a collection of (zero or more) ***Elements*** (each having a ***Descriptor***), wherein each ***Element*** has a ***Position*** (represented by an ***Int***) and a ***Name*** (represented by a ***String***). The ***Descriptor*** for ***Record {RecordDesc}*** does not impose any ordering on its ***Elements*** nor is any ordering implied by the ***Position*** of a particular ***Element*** in the ***Record***. ***Position*** is merely used for convenience to identify and retrieve a particular ***Element*** in the Record.

S = {RecordDesc}

Ω = {

Creators:

RecordDesc: ***φ → RecordDesc***

NamedRecordDesc: ***String ↪ RecordDesc***

InheritRecordDesc: ***String × List [RecordDesc, InheritanceMethod] ↪ RecordDesc***

- ***List [RecordD sc, InheritanceM thod]*** is a standard ***List*** of ***RecordDesc*** and its ***InheritanceMethod*** such that:

- each ***RecordDesc*** should have a ***Name***, which should exist in the current ***Environment*** where the ***RecordDesc*** is being created; and
- each ***InheritanceMethod*** is an ***Int*** that can hold three values representing the method of Inheritance, i.e., ***Public***, ***Private*** or ***Protected***.

For any ***RecordDesc*** – an ***Environment*** is created within it but is not mentioned explicitly. This ***Environment*** is empty to begin with – except for ***Inherited Record Descriptor*** {***InheritRecordDesc***}. Whenever an ***Element*** is added to the ***RecordDesc***, this ***Environment*** is updated to reflect it. This is consistent with the description of the ADT of ***Environment***, described further below.

Modifiers:

AddElementToRecordDesc: ***RecordDesc*** $\times$ ***String*** $\times$ ***Desc*** $\times$ ***StaticStatus*** $\times$ ***ComputableExpr*** $\times$ ***InheritStatus*** $\hookrightarrow$ ***RecordDesc***

- ***String*** represents the ***Name*** of the ***Element*** being added, while ***Desc*** represents the ***Descriptor*** that specifies its properties.
- ***InheritStatus*** is of ***Type Int*** and is similar to the Integer Value Inheritance Method used in constructing the ***Inherited Record Descriptor***.
- The ***InheritStatus*** takes one of three values, viz:

  0 – Private, i.e., not visible to any inheriting ***Desc*** and unknown to anyone outside the ***Desc***. This is preferably the default value.

  1 – Protected, i.e., visible to the inheriting ***Desc***, but unknown to anyone outside the ***Desc***.

  2 – Public, i.e., visible to the inheriting ***Desc***, and also known to anyone outside the ***Desc***.

- As the name and the values suggest, ***InheritStatus*** is used for tracking Inheritance for Classes in Object Oriented Programming Languages (OOPL).
- ***StaticStatus*** is of ***Type Bo lean*** {***B ol***} to indicate whether the ***Element*** being added is static, i.e., its value is commonly shared by all instances of the ***RecordDesc*** when it is instantiated.

<u>**Queries:**</u>

GetMaxNoOfSelfElements: ***RecordDesc*** → ***Int***

- An ***Element*** of ***RecordDesc*** can be retrieved by either its ***Name*** or its ***Position***. The ***Name*** of the ***Element*** is retrieved by its ***Position*** and then the properties of the ***Element*** are retrieved by the ***Name***.

IsSelfElement:	***RecordDesc*** × ***String*** → ***Bool***
GetSelfElementName:	***RecordDesc*** × ***Int*** ↪ ***String***
GetSelfElementDesc:	***RecordDesc*** × ***String*** ↪ ***Desc***
GetSelfElementInheritStatus:	***RecordDesc*** × ***String*** ↪ ***InheritStatus***
GetSelfElementStaticStatus:	***RecordDesc*** × ***String*** ↪ ***StaticStatus***
GetSelfElementTypeName:	***RecordDesc*** × ***String*** ↪ ***TypeName***
GetSelfElementDefaultExpr:	***RecordDesc*** × ***String*** ↪ ***ComputableExpr***
GetEnvironment:	***RecordDesc*** → ***Environment***
IsAccesible:	***RecordDesc*** × ***String*** → ***Bool***
GetAccessibleElementName:	***RecordDesc*** × ***Int*** ↪ ***String***
GetAccessibleElementDesc:	***RecordDesc*** × ***Int*** ↪ ***Desc***

GetMaxNoOfAccessibl Elements:RecordDesc → ***Int***

- ***AccessibleElement*** is that whose ***InheritStatus*** is ***Public*** – i.e., the ***Element*** is accessible outside the ***Descript r*** – irrespective of whether it is a ***SelfElement*** or an ***Element*** inherited from one of its parents.

Queries for Inheritance:

GetMaxNoOfBaseDescriptors:	***RecordDesc*** $\rightarrow$ ***Int***
GetBaseDescriptor:	***RecordDesc*** $\times$ ***Int*** $\hookrightarrow$ ***RecordDesc***
GetBaseInheritanceMethod:	***RecordDesc*** $\times$ ***Int*** $\hookrightarrow$ ***InheritanceMethod***

}

Axioms:

{

Let ***r*** be an instance of ***RecordDesc.***

Let ***s*** be an instance of ***String.***

Let ***d*** be an instance of ***Desc.***

Let ***n*** be an instance of ***Int***

Let ***y*** be ***InheritStatus.***

Let ***b*** be ***StaticStatus.***

Let ***c*** be an instance of ***ComputableExpr.***

Let ***L*** be an instance of ***List*** of ***m RecordDescs*** R_1 to R_m and their corresponding ***InheritanceMethods*** I_1 to I_m indexed by ***k.***

GetInnerTypeName (r) = RECORD

IsEmpty (GetEnvironment (RecordDesc ())) = T
IsEmpty (GetEnvironment (NamedRecordDesc (s))) = T

- A ***RecordDesc*** created by inheriting is not empty – as it inherits all the elements of the source ***RecordDesc.***

IsEmpty (GetEnvironment (Inh ritRecordDesc (s, L))) = F

GetInUseCount (RecordD sc ()) = 0

G tInUseC unt (NamedR c rdDesc (s)) = 0

GetInUseC unt (InheritRec rdDesc (s, L)) = 0

IsEmpty(GetEnvironment(AddElementToRecordDesc (r, s, d, b, c, y))=F

GetMaxNumberOfSelfElements (RecordDesc ()) = 0

GetMaxNumberOfSelfElements (NamedRecordDesc (s)) = 0

GetMaxNumberOfSelfElements (InheritRecordDesc (s, L)) = 0

GetMaxNumberOfSelfElements (r) = n IMPLIES
GetMaxNumberOfSelfElements (AddElementToRecordDesc
(r, s, d, b, c, y)) = n+1

IsSelfElement (AddElementToRecordDesc (r, s, d, b, c, y), s) = T

GetSelfElementDesc (AddElementToRecordDesc (r, s, d, b, c, y), s) = d

GetSelfElementStaticStatus
(AddElementToRecordDesc (r,s,d,b,c,y),s) = b

GetSelfElementDefaultExpr
(AddElementToRecordDesc (r, s, d, b, c, y), s) = c

GetSelfElementInheritStatus
(AddElementToRecordDesc (r, s, d, b, c, y), s) = y

GetSelfElementTypeName (r, s) =
GetInnerTypeName (GetSelfElementDesc (r, s))

Let ***r1*** and ***r2*** be instances of ***RecordDesc***.

IsEqual (r1, r2) This Equality **Axiom** is equivalent to the following conditions being satisfied:

(

GetTypeNam (r1) = DESCRIPTOR = *G tTypeName (r2);*

AND

GetInn rTypeName (r1) = RECORD = *G tInnerTyp Name (r2);*

AND

EqualString (GetName (r1), GetName (r2)) = T;

AND

GetMaxNoOfSelfElements (r1) = GetMaxNoOfSelfElements (r2);

AND

EqualString (GetSelfElementName (r1, n),
GetSelfElementName (r2, n)),
For all $1 \le n \le$ *GetMaxNoOfSelfElements(r1);*

AND

GetSelfElementInheritStatus(r1, n) =
GetSelfElementInheritStatus(r2, n)
For all $1 \le n \le$ *GetMaxNoOfselfElements (r1);*

AND

GetSelfElementStaticStatus (r1, n) =
GetSelfElementStaticStatus (r2, n)
For all $1 \le n \le$ *GetMaxNumberOfSelfElements (r1);*

AND

(IsEqual
(GetSelfElementDesc (r1, n), GetSelfElementDesc (r2, n)) = T)
For all $1 \le n \le$ *GetMaxNoOfSelfElements (r1);*

AND

GetMaxNoOfBaseDescriptors (r1) =
GetMaxNoOfBaseDescriptors (r2);

AND

(IsEqual
(GetBaseDescriptor (r1, n), GetBaseDescriptor (r2, n)) = T)
For all $1 \le n \le$ *GetMaxNoOfBaseDescriptors (r1);*

AND

GetBaseInheritanceMethod (r1, n)
= GetBaseInheritanceMethod (r2, n)
For all $1 \le n \le$ *GetMaxNoOfBaseDescriptors (r1)*

)

Axioms for Inheritance:

The following table contains ***InheritanceMethod*** of the base ***RecordDesc*** against the ***InheritStatus*** of the individual ***elements*** of that ***RecordDesc***. According to this table, only those ***Elements*** having (***InheritStatus = Public***) and (***InheritanceMethod = Public***) of the ***Descriptor*** are accessible.

InheritanceMethod of Parent	*InheritStatus of Individual Elements*		
	Private	*Protected*	*Public*
Private	***Private***	***Private***	***Private***
Protected	***Private***	***Protected***	***Protected***
Public	***Private***	***Protected***	***Public***

Let ***s*** be the names of all ***SelfElements*** in ***r*** and the entire base ***Record Descriptors*** of ***r.***

GetMaxNoOfAccessibleElements (r) =

Total Number of all those ***Elements*** for which

(***GetSelfElementInheritStatus (r, s) = Public)***

- For an inheriting ***RecordDesc***, its ***Maximum Number of Self Elements*** {***MaxNumberOfSelfElements***} (immediately after its creation) is always zero, as specified in the <u>**Axiom**</u> on ***GetMaxNumberOfSelfElements (d)*** in the previous section.
- It is possible to add more ***Elements*** to the inheriting ***RecordDesc*** subject to the <u>**Precondition**</u> that ***GetInUseCount (RecordDesc) = 0.***
- If in the case of Multiple Inheritance (***List[RecordDesc, InheritMethod]*** contains more than one ***RecordDesc***) the ***Names*** of one or more ***Elements*** clash in at least two **RecordDesc** in the **List**, then they are differentiated by appending to it the **Name** of the **RecordDesc** where they came from. This ensures uniqueness of ***Names***. The uniqueness of

Names in the inheriting ***Rec rdDesc*** is checked by the <u>**Query**</u> ***IsS IfElement***.

GetInUseC unt (r) = n ***Implies***

GetInUseCount (GetBaseDescriptor(InheritRecordDesc(s, L), k)

= n + 1,

for all ***Record Descriptors r*** in the **List *L*** indexed by ***k***.

- This <u>**Axiom**</u> ensures that the ***InUseCount*** of all the ***RecordDescs*** from which it inherits (i.e., all the ***RecordDescs*** in ***L***) is incremented upon creating a ***RecordDesc*** by the <u>**Creator**</u> ***InheritRecordDesc (s, L)***.

}

<u>**Preconditions:**</u>

{

Let ***r*** be an instance of ***RecordDesc***.

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***Desc***.

Let ***n, m, f*** be an instance of ***Int***

Let ***y*** be ***InheritStatus***.

Let ***b*** be ***StaticStatus***.

Let ***e*** be an instance of ***Environment***, where the ***RecordDesc*** is being created.

Let ***L*** be an instance of ***List*** of ***m RecordDesc*** R_1 to R_m and their corresponding ***InheritanceMethods*** I_1 to I_m indexed by ***k***.

NamedRecordDesc (s)

Requires: ***IsEmpty (s) = F;*** ***AND***

GetTypeName (R_k) = `DESCRIPTOR;` ***AND***

IsNamePresent (e, s) = F

InheritRecordDesc (s, L)

Requires: **For all** R_k **such that** $1 \leq k \leq m$:

IsEmpty (s) = F;

AND

IsNamePresent (e, s) = F;

AND

GetInnerTypeName (R_k) = RECORD ;

AND

IsEmpty (GetName (R_k)) = F ;

AND

IsNamePresent (e, GetName (R_k)) = T

AddElementToRecordDesc (r, s, d, b, c, y)

Requires: ***IsEmpty (s) = F; AND***

GetInUseCount (r) = 0 ; AND

IsSelfElement (r, s) = F

GetSelfElementName (r, n)

Requires: ***1 ≤ n ≤ GetMaxNumberOfSelfElements (r)***

GetSelfElementDesc (r, s)

GetSelfElementTypeName (r, s)

GetSelfElementInheritStatus (r, s)

GetSelfElementStaticStatus (r, s)

GetSelfElementDefaultExpr (r, s)

The previous five <u>Preconditions</u> all require: ***IsSelfElement (r, s) = T***

GetAccessibleElementName (r, n)

GetAccessibleElementDesc (r, n)

The previous two <u>Preconditions</u> require:

1 ≤ n ≤ GetMaxNumberOfAccessibleElements (r)

<u>**Preconditions for Inheritance:**</u>

GetBaseDescriptor (r, n)

GetBas InheritanceMethod (r, n)

The previous two **Preconditions for Inheritance** require:

$1 \leq n \leq$ ***GetMaxNumberOfBas Descriptors (r)***

}

ADT for the Descriptor for Function

A ***Function*** is defined as having the following properties:

- an ***Int*** representing the ***Maximum Number of Arguments***, wherein the ***Int*** could be zero;
- for each ***Argument*** (if any), a valid ***Descriptor***;
- a ***Return Type*** (specified by a valid ***Descriptor***).

S = {***FunctionDesc***}

Ω = {

Creators:

FunctionDesc: ***Desc*** × ***Int*** × ***List[Arguments]*** ↪ ***FunctionDesc***

NamedFunctionDesc: ***String*** × ***Desc*** × ***Int*** × ***List[Arguments]*** ↪ ***FunctionDesc***

- The ***Desc*** Parameter stands for the ***Return Type Descriptor*** of the ***Function***.
- The ***Int*** Parameter stands for the number of ***Arguments***.
- The ***List*** is a standard list of ***Arguments***, such that each ***Argument*** contains:
  - a ***Name*** (every argument may not have it – in which case it will be empty);
  - a ***Descriptor*** for the type of the ***Argument***; and
  - a ***Computable Expression*** that stands for the default ***Value*** of the ***Argum nt***. (***Value*** is a ***Type*** that is described further below. Not every Argument may have it – in which case it is `Void`.)

A ***Block*** for the ***FunctionDesc*** is created here but is not mentioned explicitly. Each ***Bl ck*** has an ***Environment***. This ***Block/Environment*** is updated to reflect all the arguments passed by the constructor. This is consistent with the description of the ADT of ***Block/Environment*** described in detail further below.

Modifiers:

SetArgumentName: ***FunctionDesc × Int × String → FunctionDesc***

Queries:

GetMaxNumberOfArguments: FunctionDesc → Int

GetNameForArgument: ***FunctionDesc × Int ↪ String***

GetDescForArgument: ***FunctionDesc × Int ↪ Desc***

GetExpForArgument: ***FunctionDesc × Int ↪ ComputableExpr***

GetReturnTypeDesc: ***FunctionDesc → Desc***

GetReturnTypeName: ***FunctionDesc → TypeName***

GetBlock: ***FunctionDesc → Block***

- ***Block*** is a ***Type***, described in detail further, that represents the default ***Code*** for that ***Function*** and is available (as default) for every ***Function***. It is possible that ***Block*** could contain nothing.

}

Axioms:

{

Let ***f*** be an instance of ***FunctionDesc.***

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***Desc***.

Let ***n*** be an instance of ***Int***

Let ***L*** be an instance of ***List*** of ***m Arguments*** A_1 to A_m indexed by ***k***.

G tInnerTypeNam (f) = FUNCTION

GetReturnTypeDesc (FunctionDesc (d, n, L)) = d

GetReturnTypeDesc (NamedFunctionDesc (s, d, n, L)) = d

GetReturnTypeName (f) = GetInnerTypeName (GetReturnTypeDesc (f))

GetMaxNumberOfArguments (FunctionDesc (d, n, L)) = n

GetMaxNumberOfArguments (NamedFunctionDesc (s, d, n, L)) = n

GetInUseCount (FunctionDesc (d, n, L)) = 0

GetInUseCount (NamedFunctionDesc (s, d, n, L)) = 0

GetNameForArgument (SetArgumentName (f, n, s), n) = s

GetNameForArgument (FunctionDesc (d, n, L), k) = A_k

GetNameForArgument (NamedFunctionDesc (s, d, n, L), k) = A_k

GetDescForArgument (FunctionDesc (d, n, L), k) = A_k

GetDescForArgument (NamedFunctionDesc (s, d, n, L), k) = A_k

GetExpressionForArgument (FunctionDesc (d, n, L), k) = A_k

GetExpressionForArgument (NamedFunctionDesc (s, d, n, L), k) = A_k

- In the previous six **Axioms** above, A_k stands for the k^{th} ***Argument*** of the ***List L*** from which the ***Name*** or ***Descriptor*** or ***Computable Expression*** is extracted.

Let ***f1*** and ***f2*** be instances of ***FunctionDesc.***

IsEqual (f1, f2) This Equality **Axiom** is equivalent to the following conditions being satisfied:

(

GetTyp Nam (f1) = DESCRIPTOR = ***GetTypeName (f2);***

AND

GetInn rTypeName (f1) = FUNCTION *= GetInnerTypeName (f2);*

AND

IsEqual (GetR turnTypeDesc (f1), GetReturnTypeDesc (f2)) = T;

AND

GetMaxNumberOfArguments(f1) = GetMaxNumberOfArguments(f2);

AND

(GetMaxNumberOfArguments (f1) = 0;

OR

(IsEqual (GetDescForArgument (f1, n),

GetDescForArgument (f2, n)) = T,

For all *1 ≤ n ≤ GetMaxNumberOfArguments (f)*

)

)

)

}

Preconditions:

{

Let ***f*** be an instance of ***Function.***

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***Desc***.

Let ***n*** be an instance of ***Int***

FunctionDesc (d, n, L)

NamedFunctionDesc (s, d, n, L)

The previous two **Preconditions** require:

n = size of ***L; AND***

parameter names, if existing, should be unique.

GetNameForArgument (f, n)

GetDescForArgument (f, n)

GetExpressionF rArgument (f, n)

The previous three **Preconditions** require:

$1 \le n \le$ ***GetMaxNumberOfArguments (f)***

}

The next classes (***Types***) to be discussed together as a group includes ***Values***, ***Constants***, ***Locations*** and ***Variables***. The reason being that these classes are connected intimately, with the binding factors being the ***Types***. As previously noted above, for ***Basic Computable Types***, a ***Value*** is constructed from a `TypeName` and a `MetaValue`, which can be interpreted by corresponding ***Types*** of the Meta Language. For all practical purposes, ***Value*** and `MetaValue` are the same. However, from a theoretical perspective, once a ***Value*** is constructed from `MetaValue`, it is used as a basic ***Value*** of the Target Language in the present inventive framework. `MetaValue` hierarchy of the Meta Language reflects the ***Value*** hierarchy of the Target Language.

ADT for Value

Value represents the ***Runtime Value*** (***RValue***). This is in contrast to the ***Static Value*** (***SValue***) that is more applicable to program text of a ***Type*** referred to as ***Command***, discussed in detail further below. The ***Environment*** knows ***Values*** as instances of ***Basic Computable Types***. This set of ***Values*** is further classified into ***Value Integer*** {***ValueInt***}, ***Value Real*** {***ValueReal***}, ***Value Boolean*** {***ValueBool***}, ***Value Character*** {***ValueChar***}, ***Value String*** {***ValueString***}, ***Value Address*** {***ValueAddress***}, and ***Value Void*** {***ValueVoid***}, as shown in Figure 5.

The specific algebraic specification for the base ***Value*** is defined as follows:

S = {***Value***}

Ω = {

<u>**Creators:**</u> None.

- Each individual kind of ***Value*** has its own <u>Creators</u>, as specified in their respective specific ADTs.

<u>**Modifiers:**</u> None

<u>**Queries:**</u>

IsEqual: ***Value × Value ↪ Bool***

GetTypeName: ***Value →TypeName***
GetInnerTypeNam : ***Value →TypeName***
GetCompTypeName: ***Value →TypeName***

Print: ***Value →String***
GetDesc: ***Value →BasicCompTypeDesc***

- The **Creators** for each individual kind of ***Value*** will ensure the appropriate ***TypeName*** being set, hence there is no need for a ***SetTypeName*** Modifier.

}

Axioms:

{

Let ***v*** be an instance of ***Value***.

GetTypeName (v) = VALUE
GetInnerTypeName (v) = GetCompTypeName (v)

}

Preconditions:

{

These are basic **Preconditions** – which will be extended (if required) by each of the individual kinds of ***Value*** ADTs, as described further below.

Let ***v1***, ***v2*** be instances of ***Value***.

IsEqual (v1, v2) This **Axiom** requires the following conditions be satisfied:

GetTypeName (v1) = VALUE ***= GetTypeName (v2); AND***

GetCompTypeName (v1) = GetCompTyp Nam (v2)

}

Now the properties associated with each individual kind of **Value** will be addressed.

ADT for Value Boolean

***S* = {*ValueBool*}**

***Ω* =** {

Creators:

CreateValueBool: **`MetaValueBool`** × ***BasicCompTypeDesc* ↪ *ValueBool***

Modifiers: None

Queries:

GetBool: ***ValueBool* → *Bool***

}

Axioms:

{

Let ***v***, ***v1***, ***v2*** be instances of ***ValueBool***.

Let **`mb`** be an instance of **`MetaValueBool`**.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

GetInnerTypeName (v) = BOOL

GetCompTypeName (v) = BOOL

GetBool (CreateValueBool (**`mb`**, ***d))*** = **`mb`**

IsEqual (v1, v2) This Equality **Axiom** is equivalent to the following condition being satisfied:

EqualBool (GetBool (v1), GetBool (v2))

GetDesc (CreateValueBool (mb, d)) = d

}

Preconditions:

{

Let ***v1***, ***v2*** be instances of ***ValueBool***.

Let **mb** be an instance of **`MetaValueBool`**.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2); AND***

GetCompTypeName (v1) = BOOL = ***GetCompTypeName (v2)***

CreateValueBool (mb, d)

Requires: ***GetCompTypeName (d)*** = BOOL

}

ADT for Integer Value

S = {***ValueInt***}

Ω = {

Creators:

CreateValueInt: **`MetaValueInt`** × ***BasicCompTypeDesc*** ↪ ***ValueInt***

Modifiers: None

Queries:

GetInt: ***ValueInt → Int***

GetReal: ***ValueInt → Real***

- This is possible because every ***Int*** is a ***R al*** in the Target Language as well as the Meta Language (i.e., a **`MetaValueInt`** is also a **`MetaValueReal`**).

}

Axioms:

{

Let ***v***, ***v1***, ***v2*** be instances of ***ValueInt***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let **`mi`** be an instance of **`MetaValueInt`**.

Let **`mr`** be an instance of **`MetaValueReal`**.

GetInnerTypeName (v) = `INT`

GetCompTypeName (v) = `INT`

GetInt (CreateValueInt (`mi`***))*** = `mi`

GetReal (CreateValueInt (`mi`***))*** = `mr`

IsEqual (v1, v2) This Equality **Axiom** is equivalent to the following condition being satisfied:

EqualInt (GetInt (v1), GetInt (v2))

GetDesc (CreateValueInt (`mi`***, d))*** = ***d***

}

Preconditions:

{

Let ***v1***, ***v2*** be instances of ***ValueInt***.

Let **`mi`** be an instance of **`MetValueInt`**.

Let ***d*** be an instance of ***BasicCompTyp Desc***.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2); AND***

GetCompTypeName (v1) = INT = ***GetCompTypeName (v2)***

CreateValueInt (`mi`, ***d)***

Requires: ***GetCompTypeName (d)*** = INT

}

ADT for Value Real

S = {***ValueReal***}

Ω = {

Creators:

CreateValueReal: `MetaValueReal` × ***BasicCompTypeDesc*** ↪ ***ValueReal***

Modifiers: None

Queries:

GetIntFloor: ***ValueReal*** → ***Int***

GetIntCeil: ***ValueReal*** → ***Int***

GetReal: ***ValueReal*** → ***Real***

}

Axioms:

{

Let ***v, v1, v2*** be instances of ***ValueReal***.

Let `mi`, `mj` be instances of `MetaValueInt`.

Let `mr` be an instance of `MetaValueReal`.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

GetInnerTypeName (v) = REAL

GetCompTypeName (v) = REAL

GetReal (CreateValueReal (`mr`)***)*** = `mr`

GetIntFloor (CreateValueReal (`mr`)***)*** = `mi`

GetIntCeil (CreateValueReal (`mr`)***)*** = `mj`

GetIntFloor (v) $\leq$ ***GetIntCeil (v)***

IsEqual (v1, v2) This Equality __Axiom__ is equivalent to the following condition being satisfied:

EqualReal (GetReal (v1), GetReal (v2))

GetDesc (CreateValueReal (`mr`, ***d)) = d***

}

__Preconditions:__

{

Let ***v1***, ***v2*** be instances of ***ValueReal***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let `mr` be an instance of `MetaValueReal`.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2);***

AND

GetCompTypeName (v1) = REAL;

AND

(GetCompTypeName (v2) = INT ; ***OR GetCompTypeName (v2)*** = REAL***))***

***CreateValueReal* (`mr`, *d*)**

Requires: ***GetC mpTypeNam* (*d*) = REAL**

}

__ADT for Value Character__

S = {***ValueChar***}

Ω = {

Creators:

CreateValueChar: **`MetaValueChar`** × ***BasicCompTypeDesc*** ↪ ***ValueChar***

Modifiers: None

Queries:

GetChar: ***ValueChar*** → ***Char***

GetString: ***ValueChar*** → ***String***

- Every ***Char*** is a ***String*** in the Target Language as well as the Meta Language (i.e., a **`MetaValueChar`** is also a **`MetaValueString`**).

}

Axioms:

{

Let ***v, v1, v2*** be instances of ***ValueChar***.

Let **`mc`** be an instance of **`MetaValueChar`**.

Let **`ms`** be an instance of **`MetaValueString`**.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

***GetInnerTypeName* (*v*) = CHAR**

***GetCompTypeName* (*v*) = CHAR**

GetDesc* (*CreateValueChar* (`mc`, *d*)) = *d

***GetChar* (*CreateValueChar* (`mc`)) = `mc`**

***GetString* (*CreateValueChar* (`mc`)) = `ms`**

IsEqual (v1, v2) This Equality **Axiom** is equivalent to the following condition being satisfied:

EqualChar (GetChar (v1), G tChar (v2))

}

Preconditions:

{

Let ***v1***, ***v2*** be instances of ***ValueChar***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let `mc` be an instance of `MetaValueChar`.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2); AND***

(GetCompTypeName (v1) = CHAR = ***GetCompTypeName (v2))***

CreateValueChar (mc, ***d***)

Requires: ***GetCompTypeName (d)*** = CHAR

}

ADT for Value String

S = {***ValueString***}

Ω = {

Creators:

CreateValueString: `MetaValueString` × ***BasicCompTypeDesc*** ↪ ***ValueString***

Modifiers: None

Queries:

GetString: ***ValueString*** → ***String***

}

Axioms:

{

Let ***v***, ***v1***, ***v2*** be instances of ***ValueString***.

Let `ms` be an instance of `MetaValueString`.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

GetInnerTypeName (v) = `STRING`

GetCompTypeName (v) = `STRING`

GetString (CreateValueString (`ms`***))*** = `ms`

IsEqual (v1, v2) This Equality **Axiom** is the equivalent of the following condition being satisfied:

EqualString (GetString (v1), GetString (v2))

GetDesc (CreateValueString (`ms`***, d)) = d***

}

Preconditions:

{

Let ***v1***, ***v2*** be instances of ***Value***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let `ms` be an instance of `MetaValueString`.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = `VALUE` = ***GetTypeName (v2);***

AND

GetCompTypeName (v1) = `STRING`;

AND

(GetCompTypeName (v2) = `CHAR`; ***OR GetCompTypeName (v2)*** = `STRING`***)***

CreateValu String (`ms`, ***d***)

Requires: ***GetCompTypeNam (d)*** = `STRING`

}

ADT for Value Address

This definition of ***ValueAddress*** fits the notion of ***Addresses*** connected with ***Pointers*** in the sense that ***ValueAddress*** is the ***Value*** of ***TypePointer*** (apart from being the ***Value*** of ***Address*** which is a ***Basic Computable Type***).

S = {***ValueAddress***}

Ω = {

Creators:

CreateValueAddress: **`MetaValueAddress`** × ***BasicCompTypeDesc*** ↪ ***ValueAddress***

ValueAddress is constructed in one of two ways viz:

- Explicitly: ***ValueAddress*** is constructed from a **`MetaValueAddress`** whenever there is an ***Address Constant*** in the program text; or
- Implicitly: The ***Environment*** allocates a new ***ValueAddress*** to any ***Variable*** (or ***Function***) that is created in it.

Modifiers: None

Queries:

GetAddress: ***ValueAddress*** → ***Address***

GetInt: ***ValueAddress*** → ***Int***

- ***Addresses*** are treated as ***Integers*** as a matter of convenience because in Hardware and Operating Systems these ***Addresses*** are in the Virtual (or Real) Address Space (which are always positive integer values). Hence, **`MetaValueAddress`** also happens to be the same as ***Int***.

}

Axioms:

{

Let ***v***, ***v1***, ***v2*** be instances of ***ValueAddress***.

Let **ma** be an instance of **MetaValueAddress**.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

GetInnerTypeName (v) = ADDRESS

GetCompTypeName (v) = ADDRESS

GetAddress (CreateValueAddress (**ma**, ***d)) =*** **ma**

IsEqual (v1, v2) This Equality Axiom is equivalent to the following condition being satisfied:

EqualInt (GetInt (GetAddress (v1)), GetInt (GetAddress (V2)))

GetDesc (CreateValueAddress (**ma**, ***d)) = d***

}

Preconditions:

{

Let ***v1***, ***v2*** be instances of ***Value***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let **ma** be an instance of **MetaValueAddress**.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2); AND***

GetCompTypeName (v1) = ADDRESS = ***GetCompTypeName (v2)***

CreateValueAddress (**ma**, ***d)***

Requires: ***GetCompTypeName (d)*** = ADDRESS

}

ADT for Value Void

S = {*ValueVoid*}

Ω = {

Creators:

CreateValueVoid: ***BasicCompTypeDesc ↪ ValueVoid***

Modifiers: None

Queries:

GetValueVoid: ***ValueVoid → Void***

}

Axioms:

{

Let ***v***, ***v1***, ***v2*** be instances of ***ValueVoid***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

GetInnerTypeName (v) = `VOID`

GetCompTypeName (v) = `VOID`

GetDesc (CreateValueVoid (d)) = d

GetValueVoid (v) = `Null`

- `Null` is a `MetaValueVoid` and the only one. It represents anything that is undefined or not explicitly be given any ***Value***.
- It also represents the default ***Value*** of ***Variables*** when they are created. A ***Variable*** having this ***Value*** is deemed uninitialized.

IsEqual (v1, v2) = F

- ***Void*** simply means undefined. Hence, this Equality Axiom has been selected as expression closest in representation.

}

Preconditions:

{

Let ***v1, v2*** be instances of ***ValueVoid***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

IsEqual (v1, v2)

Requires:

GetTypeName (v1) = VALUE = ***GetTypeName (v2); AND***

GetCompTypeName (v1) = VOID

CreateValueVoid (d)

Requires: ***GetCompTypeName (d)*** = VOID

}

ADT for Constant

Next, the algebraic specification for the base ***Constant*** and its associated individual kinds of ***Constants*** (e.g., ***IntConst***, ***RealConst***, ***BoolConst***, ***CharConst***, ***AddressConst***, ***StringConst***, ***VoidConst***) are discussed. A ***Constant*** is a binding of a ***Name*** (represented by a ***String***) to a ***Value*** without any change possible to the ***Value***. In other words, a ***Constant*** is a ***Named Value***. In addition, since ***Value*** is indicative of ***Type***, ***Constant*** is defined as a ***Named Value*** of a given ***Type***. Figure 6 is the hierarchy of the different kinds of ***Constants***.

The properties specified for the base ***Constant*** are as follows:

S = {***IntConstant, RealConst, BoolConst, CharConst, AddressConst, StringConst, VoidConst***}

Ω = {

Creators:

CreateNamedConstant: ***String*** × ***Value*** → ***Constant***

CreateConstant: ***Value*** → ***Constant***

Modifiers: None

Queries:

Evaluate:	***Constant → Value***
Print:	***Constant → String***
GetTypeName:	***Constant → TypeName***
GetInnerTypeName:	***Constant → TypeName***
GetCompTypeName:	***Constant → TypeName***
GetName:	***Constant → String***
IsEqual:	***Constant × Constant ↪ Bool***
GetDesc:	***Constant → Desc***

}

Axioms:

{

Let ***c, c1, c2*** be instances of ***Constant***.

Let ***s*** be an instance of ***String***.

Let ***v*** be an instance of ***Value***.

Let ***t*** be ***TypeName***.

GetTypeName (c) = CONSTANT

GetName (CreateNamedConstant (s, v)) = s

IsEmpty (GetName (CreateNamedConstant (s, v))) = F

Evaluate (CreateNamedConstant (s, v)) = v

IsEmpty (GetName (CreateConstant (v))) = T

Evaluate (CreateConstant (v)) = v

GetInnerTypeName (c) = GetInn rTypeName (Evaluate (c))

G tCompTypeName (c) = GetCompTypeName (Evaluate (c))

IsEqual (c1, c2) This Equality **Axiom** is equivalent to the following condition being satisfied:

IsEqual (Evaluate (c1), Evaluate (c2))

GetDesc (CreateConstant (v)) = GetDesc (v)

GetDesc (CreateNamedConstant (s, v)) = GetDesc (v)

}

PreConditions:

{

Let ***c1***, ***c2*** be instances of ***Constant***.

Let ***s*** be an instance of ***String***.

Let ***e*** be an instance of ***Environment*** where the ***Constant*** is to be created.

IsEqual (c1, c2)

Requires:

GetTypeName (c1) = CONSTANT = GetTypeName (c2);

AND

GetCompTypeName (c1) = GetCompTypeName (c2)

CreateNamedConstant (s, v)

Requires:

IsNamePresent (e, s) = F; AND

IsEmpty (s) = F

}

ADT for Locations

Locations are places in the ***Environm nt*** where the ***Values*** are stored. In other words, ***Locations*** are containers in the ***Environm nt*** that can contain one of the following:

- ***Location*** of a ***Vari ble*** of ***Basic Computable Type*** or ***Pointer*** contains its ***RValue***;
- ***Location*** of a ***Vari ble*** of ***Array*** or ***Rec rd*** contains its inner member ***Elements*** (of any ***Type*** – and so on and so forth until its leaf elements which are any of the ***Basic Computable Types***). It is convenient to formalize this notion of recursive access as – each successive existence of different, but specialized, ***Environments*** (for inner ***Types***) until you get to the ***Values*** of the ***Basic Computable Types***. This is also done recursively for its contained ***Elements*** whenever a ***Variable*** of this ***Type*** is instantiated;
- ***Location*** of a ***Function*** contains the ***Block (Code)***, described further below, of the ***Function*** from which a ***Value*** can be computed. There are two types of ***Value*** viz:
    - ***Static Value (SValue)*** of the ***Function***, i.e., its ***Block (Code)***.
    - ***Runtime Value (RValue)*** that is computed at runtime by the ***Block (Code)***.

Whenever an ***Environment*** creates a ***Location*** (usually at the time of creation of a new ***Variable*** or ***Function***), it assigns a new ***ValueAddress*** to the ***Location***. However, this is not explicit in the <u>**Creator**</u> for ***Location***. The ***Environment*** then allocates this ***Location*** along with its ***ValueAddress*** to the ***Variable*** (or ***Function***) being created. Again, this is not explicit in the <u>**Creator**</u> for ***Variable*** (or ***Function***). In compiler terms, a place is assigned to a ***Variable*** at a particular ***Address*** in the Virtual Address Space, as represented in Figure 7. The hierarchy for base **Location** is found in Figure 8.

The specific algebraic specification for the base **Location** is as follows:

***S* = {*Location*}**

***Ω* =** {

<u>**Creators:**</u>

- Once again each kind of ***Location*** has its own <u>**Creators**</u>, as specified in the respective ADT for each kind of **Location**.

<u>**Modifiers:**</u> None

<u>**Queries:**</u>

GetTypeName ***Location → TypeName***

GetInnerTypeName ***L cation → Typ Name***

GetAddress: ***L cation → ValueAddress***

IsEqual: ***Location × Location → Bool***

}

Axioms:

{

Let ***x, x1, x2*** be instances of ***Location***.

GetTypeName (x) = LOCATION

IsEqual (x1, x2) This Equality Axiom is equivalent to the following conditions being satisfied:

(

EqualInt (GetInt (GetAddress (x1)), GetInt (GetAddress (x2)));

AND

GetTypeName (x1) = LOCATION = ***GetTypeName (x2);***

AND

GetInnerTypeName (x1) = GetInnerTypeName (x2)

)

}

Preconditions:

{

None

}

Now, each individual kind of ***Location*** will be specified:

ADT for Value Location

S = {***ValueLocation***}

Ω = {

Creators:

NewValu L cation: $\phi \rightarrow$ ***ValueLocation***

Modifiers:

SetValue: ***ValueLocation*** $\times$ ***Value*** $\rightarrow$ ***ValueLocation***

Queries:

GetValue: ***ValueLocation*** $\rightarrow$ ***Value***

}

Axioms:

{

Let ***vl*** be an instance of ***ValueLocation***.

Let ***v*** be an instance of a ***Value***.

GetInnerTypeName (vl) = VALUE

GetCompTypeName (GetValue (NewValueLocation ()) = VOID

- ***ValueVoid*** is the default ***Value*** indicating uninitialized ***Type***.

GetValue (SetValue (vl, v)) = ***v***

}

Preconditions:

{

None

}

ADT for Environment Location

S = {***EnvironmentLocation***}

Ω = {

Creators:

NewEnvironmentLocation: $\phi \rightarrow$ *EnvironmentLocati n*

Modifiers:

SetEnvironment: *EnvironmentLocation* $\times$ *Environment* $\rightarrow$ *EnvironmentLocation*

Queries:

GetEnvironment: *EnvironmentLocation* $\rightarrow$ *Environment*

}

Axioms:

{

Let ***el*** be an instance of any ***EnvironmentLocation***.

Let **e** be an instance of any ***Environment***.

GetInnerTypeName (el) = ENVIRONMENT

IsEmpty (GetEnvironment (NewEnvironmentLocation ())) = *T*

GetEnvironment (SetEnvironment (el, e)) = e

}

Preconditions:

{

None

}

ADT for Block Location

S = {*BlockLocation*}

Ω = {

Creators:

NewBlockLocation: $\phi \rightarrow$ *BlockLocation*

Modifiers:

SetBlock: ***Bl ckLocation × Block → BlockLocati n***

- ***SetBlock*** will be required in case of method update, or cloning from another object in case of object based approach.

Queries:

GetBlock: ***BlockLocation → Block***

}

Axioms:

{

Let ***bl*** be an instance of any ***BlockLocation***.

Let ***b*** be an instance of any ***Block***.

GetInnerTypeName (bl) = BLOCK

IsEmpty (GetBlock (NewBlockLocation ())) = T

GetBlock (SetBlock (bl, b)) = b

}

Preconditions:

{

None

}

ADT for base Variable

Like ***Constant***, ***Variable*** also has a ***Name–Value*** binding but, in addition, has a ***Name–Location*** binding as well. The binding between ***Type*** and ***Location*** is achieved through ***Variable.*** Unlike that of ***Constant***, the ***Value*** of a ***Variable*** may be changed. ***Variables*** are only applicable for those ***Types*** that have a ***Descriptor***, e.g., all ***Basic Computable Types*** and the ***Composite Types*** (e.g., ***Pointer***, ***Array***, ***Function***, &

Record). A hierarchy of the kinds of ***Variables*** is shown in Figure 9. The properties associated with the base ***Variabl*** are specified in the following ADT:

S = {***Variable***}

Ω = {

Creators: None

- Each individual kind of ***Variable*** has its own **Creators**, as specified in the respective ADT for each kind of ***Variable***.
- ***Environment*** allocates a new ***Location*** to the ***Variable*** at the time of its creation – but this is not explicit in its **Creator**.
- This ***Location*** given to a ***Variable*** does not change throughout its lifetime. The ***Variable*** can therefore be queried for its ***Location***, as well as the ***ValueAddress*** contained in that ***Location***.

Modifiers:

SetAsConstant: ***Variable → Variable***

- After executing ***SetAsConstant***, the ***Variable*** is no longer permitted a ***SetValue***, i.e., its ***Value*** cannot be changed henceforth.

Queries:

IsConstant ***Variable → Bool***

GetTypeName: ***Variable → TypeName***

GetInnerTypeName: ***Variable → TypeName***

GetAddress: ***Variable → ValueAddress***

GetLocation: ***Variable → Location***

GetName: ***Variable → String***

GetDesc: ***Variable → Desc***

Print: ***Variable → String*** (Prints ***SValue***)

}

Axioms:

{

Let ***v*** be an instance of ***Variable***.

GetAddress (v) = GetAddress (GetLocation (v))

GetTypeName (v) = VARIABLE

}

<u>Preconditions:</u>

{

None

}

<u>ADT for Basic Variable</u>

S = {***BasicVar***}

Ω = {

<u>Creators:</u>

CreateBasicVariable: ***String*** × ***BasicCompTypeDesc*** $\hookrightarrow$ ***BasicVar***

wherein, ***String*** represents the ***Name*** of the ***Variable***.

- The **<u>Creator</u>** has to invoke ***IncrInUseCount*** on the ***Descriptor***, after successful creation of the ***Variable*** – so that the ***Descriptor*** is protected from further modification.

<u>Modifiers:</u>

SetValue: ***BasicVar*** × ***Value*** $\hookrightarrow$ ***BasicVar***

<u>Queries:</u>

Evaluate: ***BasicVar*** → ***Value*** (Evaluates ***RValue***)

GetCompTypeName: ***BasicVar*** → ***TypeName***

}

Axioms:

{

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***BasicC mpTypeDesc***.

Let ***z*** be an instance of ***BasicVar***.

Let ***v*** be an instance of ***Value***.

***GetInnerTypeName (z)* = BASICVAR**

GetCompTypeName (CreateBasicVariable (s, d)) = GetCompTypeName (d)

***GetCompTypeName (Evaluate (CreateBasicVariable (s, d)) =* VOID**

- This Axiom indicates that the ***Variable*** is uninitialized after creation.

IsConstant (CreateBasicVariable (s, d)) = F

IsConstant (SetAsConstant (z)) = T

IsEqual (GetCompTypeName (z), GetCompTypeName (Evaluate (z))) = T

Evaluate (SetValue (z, v)) = v

Evaluate (z) = GetValue (GetLocation (z))

SetValue (z, v) = SetValue (GetLocation (z), v)

***GetInnerTypeName (GetLocation (z)) =* VALUE**

GetDesc (CreateBasicVariable(s, d)) = d

}

Preconditions:

{

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***BasicCompTypeDesc***.

Let ***z*** be an instance of ***BasicVar***.

Let ***v*** be an instance of ***Value***.

Let ***e*** be an instance of ***Environment*** where the ***Variable*** is to be created.

CreateBasicVariable (s, d)

Requires: ***IsEmpty (s) = F ; AND***

IsNamePresent (e, s) = F

SetValue (z, v)

Requires:

IsConstant (z) = F ; AND

(

If ***(GetCompTypeName (z) =*** VOID***)***

then

GetCompTypeName (v) ∈{ BOOL, INT, REAL, CHAR, STRING, ADDRESS, VOID }

If ***(GetCompTypeName (z) =*** INT***)***

then

GetCompTypeName (v) ∈{ VOID, INT }

If ***(GetCompTypeName (z) =*** REAL***)***

then

GetCompTypeName (v) ∈{ VOID, INT, REAL }

If ***(GetCompTypeName (z) =*** CHAR***)***

then

GetCompTypeName (v) ∈{ VOID, CHAR }

If ***(GetCompTypeName (z) =*** STRING***)***

then

GetCompTypeName (v) ∈{ VOID, CHAR, STRING }

If ***(GetCompTypeNam (z)*** = ADDRESS***)***

then

GetCompTypeName (v) $\in$**{** ADDRESS, VOID **}**

)

}

ADT for Pointer Variable

A ***Pointer*** "*points to*" or "*refers to*" an element of any ***Type***. The ***Address*** of the "*pointed to*" ***Variable*** is stored as a ***Value*** of the ***Pointer Variable***. Thus, a ***Pointer Variable*** has ***ValueAddress*** as its ***Value***. The fundamental difference between ***Address*** (a ***Basic Computable Type***) and the constructed ***TypePointer*** is that ***TypePointer*** has a "*pointed to*" ***Type*** that refers to the ***Type*** of the element being pointed to.

Assigning an ***Address*** to a ***Variable*** of ***TypePointer*** will be described next. Let ***p*** be an instance of a ***Variable*** of ***TypePointer*** (which is "*pointing to*" an ***Int***), and let ***k*** be an instance of a ***Variable*** of ***Type Int***. Now consider the assignment "***p = &k***". This assignment indicates that the ***Address*** contained in the ***Location*** of ***Variable k*** is stored as the ***Value*** of ***Variable p***. Figure 10 shows a diagrammatic representation of this assignment.

The algebraic specification of the properties associated with the ***Pointer Variable*** are defined as follows:

S = {***PointerVar***}

Ω = {

Creators:

CreatePointerVariable: ***String*** $\times$ ***PointerDesc*** ↪ ***PointerVar***

wherein, ***String*** represents the ***Name*** of the ***Variable***

- The **Creator** invokes ***IncrInUseCount*** on the ***Descriptor***, after successful creation of the ***Variable,*** so that the ***Descriptor*** is protected from further modification.

Modifiers:

SetValue: ***PointerVar*** $\times$ ***Y*** ↪ ***PointerVar***

wherein, ***Y*** is ***ValueAddress*** or ***Valu Void***

Queries:

GetPointedT Typ Name: ***PointerVar → TypeName***

Evaluate: ***PointerVar → Value*** (Evaluates ***RValue***)

GetCompTypeName: ***PointerVar → TypeName***

}

Axioms:

{

Let ***s*** be an instance of ***String***.

Let ***d*** be an instance of ***PointerDesc***.

Let ***z*** be an instance of ***PointerVar***.

Let ***v*** be an instance of ***Value***.

GetInnerTypeName (z) = POINTER

IsConstant (CreatePointerVariable (s, d)) = F

IsConstant (SetAsConstant (z)) = T

GetPointedToTypeName (CreatePointerVar(s, d)) =
GetPointedToTypeName (d)

GetCompTypeName (Evaluate (CreatePointerVariable (s, d)) = VOID

- ***PointerVar*** is uninitialized at creation.

Evaluate (SetValue (z, v)) = v

Evaluate (z) = GetValue (GetLocation (z))

SetValue (z, v) = SetValue (GetLocation (z), v)

GetInnerTypeName (GetLocation (z)) = VALUE

GetDesc (CreatePointerVariable(s, d)) = d

GetCompTypeName (CreatePointerVar(s, d)) = GetCompTypeName (d)

}

Preconditions:

{

Let ***z*** be an instance of ***PointerVar***.

Let ***v*** be an instance of ***Value***.

Let ***d*** be an instance of ***PointerDesc***.

Let ***s*** be an instance of ***String***.

Let ***e*** be an instance of ***Environment*** where the ***Variable*** is to be created.

CreatePointerVariable (s, d)

Requires:

IsEmpty (s) = F; ***AND***

IsNamePresent (e, s) = F

SetValue (z, v)

Requires: ***IsConstant (z) = F***; ***AND***

- the **Precondition** is the same as that for ***Assign*** of ***LhsElementary***, as given in the ADT for ***LhsElementary*** which is described below.

}

ADT for Array Variable

S = {***ArrayVar***}

Ω = {

Creators:

CreateArrayVariable: ***String*** × ***ArrayDesc*** ↪ ***ArrayVar***

wherein, ***String*** represents the ***Name*** of the ***Variable***.

- The <u>**Creator**</u> invokes ***IncrInUs Count*** on the ***Descriptor***, after successful creation of the ***Variable***, so that the ***Descriptor*** is protected from further modification.

<u>**Modifiers:**</u> None

<u>**Queries:**</u>

GetArrayedTypeName: ***ArrayVar → TypeName***

}

<u>**Axioms:**</u>

{

Let ***s*** be an instance of ***String***.

Let ***a*** be an instance of ***ArrayDesc***.

Let ***z*** be an instance of ***ArrayVar***.

GetInnerTypeName (z) = ARRAY

IsConstant (CreateArrayVariable (s, a)) = F

IsConstant (SetAsConstant (z)) = T

GetArrayedTypeName (CreateArrayVariable (s, a)) = GetArrayedTypeName (a)

GetDesc (CreateArrayVariable(s, d)) = d

GetInnerTypeName (GetLocation (z)) = ENVIRONMENT

}

<u>**Preconditions:**</u>

{

Let ***d*** be an instance of ***ArrayDesc***.

Let ***s*** be an instance of ***String***.

Let ***e*** be an instance of ***Environment*** where the ***Variable*** is to be created.

CreateArrayVariabl (s, d)

Requires: ***IsEmpty (s) = F; AND***

IsNamePresent (e, s) = F

}

ADT for Record Variable

S = {***RecordVar***}

Ω = {

Creators:

CreateRecordVariable: ***String*** × ***RecordDesc*** ↪ ***RecordVar***

wherein, ***String*** represents the ***Name*** of the ***Variable.***

- The **Creator** invokes ***IncrInUseCount*** on the ***Descriptor,*** after successful creation of the ***Variable,*** so that the ***Descriptor*** is protected from further modification.

Modifiers: None

Queries:

GetElementTypeName: ***RecordVar*** × ***String*** ↪ ***TypeName***

- The ***String*** represents ***Name*** of the ***Element*** whose ***TypeName*** is being queried. This query is resolved by its corresponding query on the ***RecordDesc.***

}

Axioms:

{

Let ***s*** be an instance of ***String.***

Let ***r*** be an instance of ***RecordDesc.***

Let ***z*** be an instance of ***RecordVar.***

GetInnerTypeName (z) = RECORD

IsConstant (CreateRecordVariable (s, r)) = F
IsConstant (SetAsConstant (z)) = T
GetDesc (CreateRecordVariable(s, d)) = d

GetInnerTypeName (GetLocation (z)) = ENVIRONMENT

GetElementTypeName (z, s) = GetElementTypeName (GetDesc (z), s)

}

Preconditions:

{

Let ***d*** be an instance of ***RecordDesc***.

Let **s** be an instance of ***String***.

Let **e** be an instance of ***Environment*** where the ***Variable*** is to be created.

Let ***z*** be an instance of ***RecordVar***.

CreateRecordVariable (s, d)

Requires: ***IsEmpty (s) = F; AND***
IsNamePresent (e, s) = F

GetElementTypeName (z, s)

Requires: ***IsElementOf (GetDesc (z), s) = T***

}

ADT for Function

Functions are ***Variables*** that have ***Parameters*** and ***Blocks,*** which can be invoked directly (or as ***Computable Expressions***), as described in detail further below.

__ADT for the base Accessors__

Accessors are used to reach (or access) any ***Variable*** and/or ***L cati ns*** – either via its parent ***Variables***, or indirectly via ***Locations***. ***Computable Expressions***, defined further below, are required to be of any of the ***Basic Computable Types*** (or ***Pointer***). However, one may not be able to create ***Computable Expressions*** directly from ***Variables*** or ***Functions***, because ***Variables*** may be of ***Composite Types***, e.g., ***Arrays*** or ***Records***, whereas ***Functions*** may return ***Composite Types***, e.g., ***Arrays*** or ***Records***. Hence, a lookup or conversion table for these composite ***Variables*** is required to get to the elementary ***Variable*** that can be used to build ***Computable Expressions***. The ***Accessors*** (whose ***Components*** are ***Variables***) help us perform this lookup. ***Accessors*** belong to one of the following classifications or types:

- ***Simple Accessors*** (e.g., ***VariableAccessor***) that directly access a given ***Variable*** or ***Function*** in an ***Environment***.

- ***FunctionAccessors*** built from ***FunctionVariables*** and a list of parameters where each parameter is either an ***Accessor*** or a ***ComputableExpression***. These ***Accessors*** access the ***Variable*** holding the result of the evaluation of the ***Function***.

- ***RecordElementAccessors*** built from a ***Record*** and an ***Element*** name for that ***Record***. These ***Accessors*** access the ***Element*** of the ***Record*** specified by the ***Element*** name.

- ***ArrayElementAccessors*** built from an ***Array*** and a list of ***ArithmeticExpressions*** (defined further below) that evaluates to an index into that ***Array***. These ***Accessors*** access the ***Element*** of the array.

- ***DrefAccessors*** built from ***PointerExpressions*** (defined further below). These ***Accessors*** access the ***Locations*** pointed to by ***PointerExpressions***.

The base ***Accessor*** hierarchy is shown in Figure 11. The algebraic specification of the properties specified for the base ***Accessor*** is as follows:

S = {***Accessor***}

Ω **=** {

Creators: None

- Each individual kind of ***Accessors*** has its own **Creators**, as specified in the respective ADT for each kind of ***Accessor.***

Modifiers: None

Queries:

GetTypeName: ***Accessor → TypeName***

GetInnerTypeName: ***Accessor → TypeName***

GetDesc: ***Accessor → Desc***

AccessVariable ***Accessor ↪ Variable***

AccessLocation: ***Accessor → Location***

- This method on ***Accessor*** is provided to access contents using the ***Dereferencing Accessor*** {***DrefAccessor***}. The ***DrefAccessor*** directly accesses contents of a ***Location***, (bypassing the ***Variable*** even if it is available).

IsDrefAccessor: ***Accessor → Bool***

Print: ***Accessor → String*** (This accesses the ***SValue***)

}

Axioms:

{

Let ***a*** be an instance of any ***Accessor***.

G tTypeName (a) = ACCESSOR

}

PreConditions:

{

Let ***a*** be an instance of ***Accessor***.

AccessVariable (a)

Requires: ***IsDrefAccessor (a) = F***

}

ADT for Variable Accessor

S = {***VariableAccessor***}

Ω = {

Creators:

CreateVariableAccessor: ***String ↪ VariableAccessor***

wherein, ***String*** represents the ***Name*** of the ***Variable***.

Modifiers: None

Queries: None

}

Axioms:

{

Let ***s*** be an instance of ***String***, representing the ***Name*** of the ***Variable***.

Let ***a*** be an instance of ***VariableAccessor***.

Let ***e*** be an instance of ***Environment*** where the ***Accessor*** is to be created.

GetInnerTypeName (a) = `VARIABLE`

IsDrefAccessor (CreateVariableAccessor (s)) = F

Acc ssVariable (CreateVari bleAccessor (s)) = GetVariable (e, s)

AccessLocation(CreateVariableAccessor(s)) =

GetLocation (GetVariable (e, s))

GetDesc (a) = GetDesc (AccessVariable (a))

}

PreConditions:

{

Let ***s*** be an instance of ***String***, representing the ***Name*** of the ***Variable***.

Let ***e*** be an instance of ***Environment*** where the ***Accessor*** is to be created.

CreateVariableAccessor (s)

Requires:

IsVariablePresent (e, s) = T; ***AND***

IsAccessible (e, s) = T

}

ADT for Function Accessor

The Creator uses an ***Accessor*** and a ***ParameterList*** as one of its arguments. Each parameter of the ***ParameterList*** is either a ***ComputableExpr*** or an ***Accessor***. (***ParameterList*** is a standard ***List*** and thus will not be axiomatized further).

S = {***FunctionAccessor***}

Ω = {

Creators:

CreateFunctionAccessor: ***Accessor × ParameterList ↪ FunctionAccessor***

- A ***Function*** can be an element of a ***Record*** or ***Array***, or even pointed to by a ***Pointer***. Therefore, first an ***Accessor*** will have to be created for the name of the function. This ***Accessor***, together with the ***ParameterList*** together create the ***FunctionAccessor***.

- The ***Expression f(a,b,c)*** creates a ***VariableAccess r*** for ***f*** that is passed as ***Access r*** to ***CreateFunctionAccessor*** with the ***Parameter List*** as the second parameter

Modifiers: None

Queries:

GetParameterList: ***FunctionAccessor → ParameterList***

}

Axioms:

{

Let ***a*** be an instance of ***Accessor***.

Let ***f*** be an instance of ***FunctionAccessor***.

Let ***e*** be an instance of ***Environment***.

Let ***L*** be a ***ParameterList***.

GetInnerTypeName (a) = **VARIABLE**

IsDrefAccessor (CreateFunctionAccessor (a, L)) = F

GetParameterList (CreateFunctionAccessor (a, L)) = L

AccessVariable (CreateFunctionAccessor (a, L)) = AccessVariable (a)

AccessLocation (CreateFunctionAccessor (a, L)) =
GetLocation (GetVariable (GetEnvironment (GetLocation (AccessVariable (a)))), s)
wherein, ***s*** is ***GetName (AccessVariable (a))***

GetDesc (f) = GetReturnTypeDesc (GetDesc (AccessVariable (f)))

}

PreConditions:

{

Let ***a*** be an instance of ***Accessor.***

Let **e** be an instance of ***Environment*** where the ***Accessor*** is to be created.

CreateFunctionAccessor (a, L)

Requires: ***GetInnerTypeName (GetDesc (a))*** = FUNCTION

- Each parameter in the ***ParameterList*** (***L***) is matched for its ***Type*** with the corresponding ***Arguments*** in the ***Descriptor*** for the ***Function***, subject to the presence of ***Arguments.***

}

ADT for Record Element Accessor

S = {***RecordElementAccessor***}

Ω = {

Creators:

CreateRecordElementAccessor: Accessor × ***String*** ↪ ***RecordElementAccessor***

- Suppose a ***Record Variable*** named ***R*** contains two Integer elements, ***e1*** and ***e2.*** The ***Expression R.e1*** creates a ***VariableAccessor*** for ***R*** that is passed as ***Accessor*** to ***CreateRecordElementAccessor*** with the ***String e1*** as the second parameter, while ***R.e2*** creates the ***VariableAccessor*** for ***R*** (if not already available – because the occurrence of ***R.e2*** is independent of the occurrence of ***R.e1*** and vice-versa) and is passed as a parameter with the ***String e2.***

Modifiers: None

Queries: None

}

Axioms:

{

Let ***s*** be an instance of ***String***, representing the ***Name*** of the ***Element***.

Let ***a*** be an instance of ***RecordAccessor***.

GetInnerTypeName (a) = VARIABLE

IsDrefAccessor (CreateRecordElementAccessor (a, s)) = F

AccessVariable (CreateRecordElementAccessor (a, s)) =
GetVariable (GetEnvironment (AccessLocation (a)), s)

AccessLocation (CreateRecordElementAccessor (a, s)) =
GetLocation (GetVariable (GetEnvironment (AccessLocation (a)), s))

GetDesc (CreateRecordElementAccessor (a, s)) =
GetElementDesc (GetDesc (a), s)

}

PreConditions:

{

Let ***s*** be an instance of ***String***, representing the ***Name*** of the ***Element***.

Let ***a*** be an instance of ***Accessor***.

CreateRecordElementAccessor (a, s)

Requires: ***GetInnerTypeName (GetDesc (a))*** = RECORD; and
IsAccessible (GetDesc (a), s) = T

}

ADT for Array Element Accessor

S = {***ArrayElementAccessor***}

Ω = {

Creators:

CreateArrayElementAccessor: ***Accessor*** × ***List [ArithmeticExpr]*** ↪ ***ArrayElementAccessor***

- An ***Array Variable*** has as many ***Indexes*** into it as the number of ***Dimensions*** for accessing any of its ***Elements.***
- Let ***Y*** be an array ***Variable*** of ***Real*** that has ***M Dimensions***, wherein the ***Size*** for each ***Dimension*** is (S_1, S_2, … S_M) respectively.
- The ***Expression*** to ***Index*** into ***Y*** for an ***Element*** is ***Y[***E_1, E_2, … E_M***]***, where each E_k, $(1 \le k \le M)$, evaluates to an integer between ***1*** and S_M.
- The expression ***Y[***E_1, E_2, … E_M***]*** creates a ***VariableAccessor*** for ***Y*** that is passed as ***Accessor*** to ***CreateArrayElementAccessor***, with ***[***E_1, E_2, … E_M***]*** as the ***List*** of ***ArithmeticExpr.***

Modifiers: None

Queries: None

}

Axioms:

{

Let ***ae*** be an instance of ***ArithmeticExpr***.

Let ***a*** be an instance of ***Accessor***.

Let ***L*** be a ***List [ArithmeticExpr]***.

GetInnerTypeName (a) = VARIABLE

IsDrefAccessor (CreateArrayElementAccessor (a, L)) = F

AccessVariabl (CreateArrayElementAccessor (a, L)) =

GetVariabl (GetEnvironment (AccessLocation (a)), L)

GetDesc (CreateArrayElementAccessor (a, L)) =
GetArrayedTypeDesc (GetDesc (a))

}

PreConditions:

{

Let ***a*** be an instance of ***Accessor.***

Let ***L*** be a ***List [ArithmeticExpr].***

CreateArrayElementAccessor (a, L)

Requires: ***GetInnerTypeName (GetDesc (a)) =*** ARRAY ***; AND***
EqualInt (n, GetMaxDimension (GetDesc (a))
(Where ***n*** is the number of ***Expressions*** in ***L***)

}

ADT for Dereferencing Accessor

Dereferencing Accessor {DrefAccesor} accesses a value pointed to by a pointer.

S = {***DrefAccessor***}

Ω = {

Creators:

CreateDrefAccessor: ***PointerExpr → DrefAccessor***

Modifiers: None

Queries: None

}

Axioms:

{

Let ***p*** be an instance of ***PointerExpr***.

Let ***a*** be an instance of ***DrefAccessor.***

GetInnerTypeName (a) = LOCATION

IsDrefAccessor (CreateDrefAccessor (p)) = T

AccessLocation (CreateDrefAccessor (p)) =
GetLocationForAddress (Evaluate (p))

GetDesc (CreateDrefAccessor (p)) =
GetPointedToTypeDesc (GetDesc (p))

}

PreConditions:

{

Let ***p*** be an instance of ***PointerExpr***.

CreateDrefAccessor (p)

Requires: ***GetCompTypeName (Evaluate (p))*** **IS NOT** VOID

}

ADT for the base Computable Expressions

Computable Expressions are ***Expressions*** that compute ***Values*** of ***Basic Computable Types***. Figure 12 shows the hierarchy of base ***Computable Expressions***. The algebraic specification of the properties specified for the base ***Computable Expressions*** is as follows:

S = {***ComputableExpr***}

Ω = {

Creators: None.

- Each individual kind of ***C mputable Expressi n*** has its own **Creators**, as specified in the respective ADT for each kind of ***Computabl Expression***.

Modifiers: None

Queries:

GetTypeName:	***ComputableExpr*** → ***TypeName***
GetInnerTypeName:	***ComputableExpr*** → ***TypeName***
GetCompTypeName:	***ComputableExpr*** → ***TypeName***
Evaluate:	***ComputableExpr*** →***Value*** (Evaluates ***RValue***)
Print:	***ComputableExpr*** → ***String*** (Prints ***SValue***)
GetDesc:	***ComputableExpr*** → ***BasicCompTypeDesc***

}

Axioms:

{

Let **e** be an instance of ***ComputableExpr***.

GetTypeName (e) = COMPUTABLE_EXPR

}

Preconditions:

{

None

}

ADT for Arithmetic Expression

S = { ***ArithmeticExpr*** }

Ω = {

Creators:

CreateArithmeticVariableExpression: ***Accessor ↪ ArithmeticExpr***

CreateArithmeticConstantExpression: ***X → ArithmeticExpr***

wherein, ***X*** is of ***IntConst*** or ***RealConst***

CreateArithmeticFunctionCallExpression: ***FunctionAccessor ↪ ArithmeticExpr***

CreateArithmeticDrefExpression: ***DrefAccessor ↪ ArithmeticExpr***

Arithmetic Operator Expressions:

CreateAddExpression: ***ArithmeticExpr × ArithmeticExpr → ArithmeticExpr***

CreateSubtractExpression: ***ArithmeticExpr × ArithmeticExpr → ArithmeticExpr***

CreateMultiplyExpression: ***ArithmeticExpr × ArithmeticExpr → ArithmeticExpr***

CreateDivideExpression: ***ArithmeticExpr × ArithmeticExpr ↪ ArithmeticExpr***

CreateIntDivideExpression: ***Arithm ticExpr × ArithmeticExpr ↪ Arithm ticExpr***

- This last Arithmetic Operator Expression above is required because ***Int Division*** is allowed as a special case, and it truncates the result if the first ***Int*** is not divisible by the second ***Int***

Modifiers: None

Queries:

GetSuperTypeName: ***ArithmeticExpr*** **→** ***TypeName***

- This is a private function for this ADT – that is used by ***GetComputableTypeName*** for returning ***TypeName*** according to the following table – where ***Type*** represents ***Type*** of the constituent ***ArithmeticExpr***. For unary ***ArithmeticExpr***, it is assumed that the ***Type*** of the constituent ***ArithmeticExpr*** will suffice.

TypeName	TypeName	SuperTypeName
Int	***Int***	***Int***
Int	***Real***	***Real***
Real	***Int***	***Real***
Real	***Real***	***Real***

}

Axioms:

{

Let ***a***, ***a1***, ***a2*** be instances of ***ArithmeticExpr***.

Let ***v*** be an instance of ***Accessor.***

Let ***c*** be an instance of ***Constant***.

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

GetInn rTypeName (a) = `ARITHMETIC`

GetDesc (CreateArithmeticVariableExpression (v)) = GetDesc (v)

GetDesc (CreateArithmeticFunctionExpression (f)) = GetDesc (f)
GetDesc (CreateArithmeticConstantExpressi n (c)) = GetDesc (c)
GetDesc (CreateArithmeticDrefExpression (d)) = GetDesc (d)

GetCompTypeName (a) = GetCompTypeName (GetDesc (a))
GetCompTypeName (CreateDivideExpr (a1, a2)) = REAL
GetCompTypeName (CreateIntDivideExpr (a1, a2)) = INT

}

PreConditions:

{

Let ***a***, ***a1***, ***a2*** be instances of ***ArithmeticExpr***.
Let ***v*** be an instance of ***VariableAccessor***.
Let ***f*** be an instance of ***FunctionAccessor***.
Let ***d*** be an instance of ***DrefAccessor***.

CreateDivideExpression (a1, a2)
Requires: ***Evaluate (a2)*** $\neq 0$

CreateIntDivideExpression (a1, a2)
Requires: ***Evaluate (a2)*** $\neq 0$; and
GetCompTypeName (a1) = INT; ***AND***
GetCompTypeName (a2) = INT

CreateArithmeticVariableExpression (v)
Requires:
GetInnerTypeName (v) = VARIABLE;
AND
GetInnerTypeName (GetDesc (v)) = BASICCOMPTYPE;
AND
(GetCompTypeName (GetDesc (v)) = INT;
OR
GetCompTypeName (GetDesc (v)) = REAL***)***

CreateArithmeticFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = BASICCOMPTYPE

AND

(GetCompTypeName (GetDesc (f)) = INT

OR

GetCompTypeName (GetDesc (f)) = REAL ***)***

CreateArithmeticDrefExpression (d)

Requires:

GetInnerTypeName (d) = LOCATION

AND

GetInnerTypeName (GetDesc (d)) = BASICCOMPTYPE

AND

(GetCompTypeName (GetDesc (d)) = INT

OR

GetCompTypeName (GetDesc (d)) = REAL ***)***

}

ADT for Boolean Expression

S = {***BooleanExpr***}

Ω = {

Creators:

CreateBooleanVariableExpression: ***VariableAccessor*** → ***BooleanExpr***

CreateBooleanConstantExpression: ***BoolConst*** → ***BooleanExpr***

CreateBooleanFunctionCallExpression: *FunctionAccessor* ↪ *B oleanExpr*

CreateBooleanDrefExpression: *DrefAccessor* ↪ *BooleanExpr*

CreateIsEqualArithExpr: *ArithmeticExpr* × *ArithmeticExpr* → *BooleanExpr*

CreateIsEqualBoolExpr: *BooleanExpr* × *BooleanExpr* → *BooleanExpr*

CreateIsEqualCharExpr: *CharExpr* × *CharExpr* → *BooleanExpr*

CreateIsEqualStringExpr: *StringExpr* × *StringExpr* → *BooleanExpr*

CreateIsEqualPointerExpr: *PointerExpr* × *PointerExpr* → *BooleanExpr*

CreateIsLessThanArithExpr: *ArithmeticExpr* × *ArithmeticExpr* → *BooleanExpr*

CreateIsLessThanBoolExpr: *BooleanExpr* × *BooleanExpr* → *BooleanExpr*

CreateIsLessThanCharExpr: *CharExpr* × *CharExpr* → *BooleanExpr*

CreateIsLessThanStringExpr: *StringExpr* × *StringExpr* → *BooleanExpr*

Boolean Operator Expressions:

CreateAndExpression: *BooleanExpr* × *BooleanExpr* → *Bool anExpr*

CreateOrExpression: ***BooleanExpr × Bo l anExpr → BooleanExpr***

CreateXOrExpression: ***BooleanExpr × BooleanExpr → BooleanExpr***

CreateNotExpression: ***BooleanExpr → BooleanExpr***

Modifiers: None

Queries: None

}

Axioms:

{

Let ***b*** be an instance of ***BooleanExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***c*** be an instance of ***Constant.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

GetInnerTypeName (b) = BOOL

GetCompTypeName (b) = BOOL

GetDesc (CreateBooleanVariableExpression (a)) = GetDesc (a)

GetDesc (CreateBooleanFunctionExpression (f)) = GetDesc (f)

GetDesc (CreateBooleanConstantExpression (c)) = GetDesc (c)

GetDesc (CreateBooleanDrefExpression (d)) = GetDesc (d)

}

PreConditions:

{

Let ***b*** be an instance of ***BooleanExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

CreateBooleanVariableExpression (a)

Requires:

GetInnerTypeName (a) = **VARIABLE** ;

AND

GetInnerTypeName (GetDesc (a)) = **BASICCOMPTYPE** ;

AND

GetCompTypeName (GetDesc (a)) = **BOOL**

CreateBooleanFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = **BASICCOMPTYPE** ;

AND

GetCompTypeName (GetDesc (f)) = **BOOL**

CreateBooleanDrefExpression (d)

Requires:

GetInnerTypeName (d) = **LOCATION** ;

AND

GetInnerTypeName (GetDesc (d)) = **BASICCOMPTYPE** ;

AND

GetCompTypeName (GetDesc (d)) = **BOOL**

}

ADT for Character Expression

S = {***CharExpr***}

Ω = {

Creators:

Cre teCharacterVariableExpression: ***Accessor*** ↪ ***CharExpr***

CreateCharacterConstantExpression: ***CharConst*** → ***CharExpr***

CreateCharacterFunctionCallExpression: ***FunctionAccessor*** ↪ ***CharExpr***

CreateCharacterDrefExpression: ***DrefAccessor*** ↪ ***CharExpr***

Operator Expressions:

CreatePredExpression: ***CharExpr*** → ***CharExpr***

CreateSuccExpression: ***CharExpr*** → ***CharExpr***

Modifiers: None

Queries: None

}

Axioms:

{

Let ***c*** be an instance of ***CharExpr***.

Let ***a*** be an instance of ***Accessor.***

Let c_1 be an instance of ***Constant.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

G tInn rTyp Name (c) = CHAR

GetCompTypeName (c) = CHAR

GetDesc (CreateCharacterVariableExpression (a)) = GetDesc (a)

GetDesc (CreateCharacterFunctionExpression (f)) = GetDesc (f)

G tDesc (CreateCharacterConstantExpression (c_1)) = GetDesc (c_1)

GetDesc (CreateCharacterDrefExpression (d)) = GetDesc (d)

}

PreConditions:

{

Let ***b*** be an instance of ***BooleanExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

CreateCharacterVariableExpression (a)

Requires:

GetInnerTypeName (a) = VARIABLE ;

AND

GetInnerTypeName (GetDesc (a)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (a)) = CHAR

CreateCharacterFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (f)) = CHAR

CreateCharacterDrefExpression (d)

Requires:

GetInnerTyp Nam (d) = LOCATION ;

AND

GetInnerTypeName (G tDesc (d)) = **BASICCOMPTYPE** ;

AND

GetCompTypeName (GetDesc (d)) = **CHAR**

}

ADT for String Expression

S = {***StringExpr***}

Ω= {

Creators:

CreateStringVariableExpression: Accessor ↪ StringExpr

CreateStringConstantExpression: X → StringExpr

wherein, ***X*** is ***CharConst*** or ***StringConst***

CreateStringCharExpression: CharExpr → StringExpr

CreateStringFunctionCallExpression: FunctionAccessor ↪ StringExpr

CreateStringDrefExpression: DrefAccessor ↪ StringExpr

Operator Expressions:

CreateStringConcatExpr: StringExpr × StringExpr → StringExpr

CreateSubstringExpr: StringExpr × ArithmeticExpr × ArithmeticExpr → StringExpr

- wherein, the first ***ArithmeticExpr*** is the ***Position*** of the start of the ***SubString*** within the ***String***, and the second ***Arithm ticExpr*** is the ***Length*** of the ***Substring***.

Modifiers: None

Queries: None

}

Axioms:

{

Let ***s*** be an instance of ***StringExpr***.

Let ***k*** be a ***CharExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***c*** be an instance of ***Constant.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

GetInnerTypeName (s) = STRING

GetCompTypeName (s) = STRING

GetDesc (CreateStringVariableExpression (a)) = GetDesc (a)

GetDesc (CreateStringFunctionExpression (f)) = GetDesc (f)

GetDesc (CreateStringConstantExpression (c)) = GetDesc (c)

GetDesc (CreateStringDrefExpression (d)) = GetDesc (d)

- Every ***Char*** is a ***String*** therefore ***GetDesc*** converts any input ***Descriptors*** of ***CompTypeName*** = CHAR to ***Descriptors*** of ***CompTypeName*** = STRING.

}

PreConditions:

{

Let ***s*** be an instance of ***StringExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

CreateStringVariableExpression (a)

Requires:

GetInnerTypeName (a) = VARIABLE ;

AND

GetInnerTypeName (GetDesc (a)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (a)) = STRING

CreateStringFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (f)) = STRING

CreateStringDrefExpression (d)

Requires:

GetInnerTypeName (d) = LOCATION ;

AND

GetInnerTypeName (GetDesc (d)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (d)) = STRING

}

__ADT for Pointer Expression__

S = {***PointerExpr***}

Ω= {

__Creators:__

CreatePointerVariableExpression: ***Accessor*** ↪ ***PointerExpr***

CreatePointerFunctionCallExpression: ***FunctionAccessor ↪ PointerExpr***

CreatePointerReferenceExpression: ***Accessor → PointerExpr***

CreatePointerDrefExpression: ***DrefAccessor → PointerExpr***

Operator Expressions:

CreatePointerAdvanceExpression: ***PointerExpr × ArithmeticExpr ↪ PointerExpr***

- wherein, the ***ArithmeticExpr*** is the number by which the ***Value*** of the ***PointerExpr*** is to be advanced (or incremented).

Modifiers: None

Queries:

GetInnerTypeDesc: PointerExpr → Descriptor

- Since ***Pointer*** is also a ***BasicCompType***, the ***GetDesc()*** query on ***PointerExpression*** will return a ***BasicCompTypeDesc***, with ***CompTypeName*** as ADDRESS.
- However, for type checking, the inner type of the ***Pointer*** is required. For Example, a ***Pointer*** to ***Int***, can only be assigned to a variable of type ***Pointer*** to ***Int***.
- A new query ***GetInnerTypeDesc()*** is introduced for type checking in assignments which returns the inner (pointed to) type of the pointer.

}

Axioms:

{

Let ***p*** be an instance of ***PointerExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

G tInnerTypeName (c) = POINTER

GetInnerTypeDesc (CreatePointerVariableExpression (a)) = GetDesc (a)
GetInnerTypeDesc (CreatePointerFunctionExpression (f)) = GetDesc (f)

GetInnerTypeDesc (CreatePointerReferenceExpression (a)) = GetDesc (a)

GetInnerTypeDesc (CreatePointerDrefExpression (d) = GetDesc (d)
GetCompTypeName (p) = ADDRESS

}

PreConditions:

{

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***a*** be an instance of any ***Accessor.***

Let ***d*** be an instance of ***DrefAccessor.***

CreatePointerReferenceExpression (a)

Requires: ***IsDrefAccessor (a) = F***

CreatePointerVariableExpression (a)

Requires:

GetTypeName (GetDesc (a)) = DESCRIPTOR;

AND

GetInnerTypeName (GetDesc (a)) = POINTER;

AND

GetInnerTypeName (a) = VARIABLE

CreatePointerFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = POINTER

CreatePointerDrefExpression (d)

Requires:

GetInnerTypeName (GetDesc (d)) = POINTER;

AND

GetInnerTypeName (d) = LOCATION

}

ADT for Void Expression

Since ***Void*** is also a ***BasicCompType***, the ***GetDesc()*** query on ***VoidExpression*** will return a ***BasicCompTypeDesc***, with ***CompTypeName*** as VOID. ***VoidExpressions*** are required to incorporate Dynamic Typing capabilities in the Generic Typed DGC Classes Framework, as well as to create meaningful expressions of Procedure Calls, which do not have a return ***Value***.

S = {***VoidExpr***}

Ω = {

Creators:

CreateVoidVariableExpression:	***Accessor ↪ VoidExpr***
CreateVoidConstantExpression:	***VoidConst → VoidExpr***
CreateVoidFunctionCallExpression:	***FunctionAccessor ↪ VoidExpr***
CreateVoidDrefExpression:	***DrefAccessor → VoidExpr***

Operator Expressions: None

Modifiers: None

Queries: None

}

Axioms:

{

Let ***v*** be an instance of ***VoidExpr***.

Let ***a*** be an instance of ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***d*** be an instance of ***DrefAccessor.***

GetInnerTypeName (GetDesc (v)) = BASICCOMPTYPE

GetCompTypeName (GetDesc (v)) = VOID

}

PreConditions:

{

Let ***a*** be an instance of any ***Accessor.***

Let ***d*** be an instance of ***DrefAccessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***v*** be an instance of ***VariableAccessor.***

CreateVoidFunctionCallExpression (f)

Requires:

GetInnerTypeName (GetDesc (f)) = BASICCOMPTYPE ;

AND

GetCompTypeName (GetDesc (f)) = VOID

CreateVoidVariableExpression (v)

Requires:

GetInnerTypeName (GetDesc (v)) = BASICCOMPTYPE ;

AND

G tC mpTypeName (GetDesc (v)) = VOID

CreateVoidDrefExpression (d)

Requires:

GetInnerTyp Name (GetDesc (d)) = BASICCOMPTYPE ;

AND

GetCompTypeNam (GetDesc (d)) = VOID

}

ADT for base Left Hand Side Identifier

The ***Left-Hand-Side-Identifier*** (***LhsId***), found only on the Left-Hand-Side of an ***Assignment*** statement, is the only thing that performs a ***SetValue*** on ***Variable*** or ***Location*** thereby causing a change of ***State***. ***LhsId*** uses the ***Accessor*** to get to a ***Variable/Location***. The ***LhsId*** hierarchy is found in Figure 13.

LhsId is used for the following purposes:

- In its simplest form, ***LhsId*** contains a ***Variable*** (or a ***Location*** of ***Variable***) of ***Basic Computable Type*** or ***Pointer***. It performs a ***SetValue*** on this ***Variable***, thereby changing ***State***;

LhsId may contain a ***Variable*** of ***Record*** or ***Array***. In this case, ***LhsId*** iterates through the ***Variable*** and performs a ***SetValue*** (for Deep Copy) on the individual elements of the ***Array*** or ***Record***. Deep Copy is the term used for copying of Composite Variables, e.g., Array or Record, that contain Element Variables. That is, Deep Copy implies the copying of corresponding Element Variables of that Composite Variable. If the Element Variables are Composite Variables themselves, then Deep Copying involves recursively copying their elements (i.e., Composite Variables).

- ***LhsId*** may contain a ***Variable*** of ***Function***. In this case, ***LhsId*** performs a ***SetBlock*** on the ***Function Variable***. This is required only in case of method update for advanced Object-Oriented Languages.

ADT for base LhsId

S = {***LhsId***}

Ω = {

Creators: None

- Each individual kind of ***LhsIds*** has its own <u>**Creators**</u>.

<u>**Modifiers:**</u>

Assign: ***LhsId*** $\times$ ***X*** $\hookrightarrow$ ***LhsId***

wherein, ***X*** is either a ***ComputableExpr*** or an ***Accessor.***

<u>**Queries:**</u>

Print: ***LhsId*** $\rightarrow$ ***String*** (Prints ***SValue***)

GetDesc: ***LhsId*** $\rightarrow$ ***Desc***

GetAccessor:LhsId $\rightarrow$ ***Accessor***

}

<u>**Axioms**</u>:

{

Let ***Id*** be an instance of ***LhsId***.

GetDesc (Id) = GetDesc (GetAccessor (Id))

- The ***Descriptor*** is the same, not two ***Descriptors*** which are equal to each other.

GetTypeName (Id) = **LHSID**

}

<u>**PreConditions**</u>:

{

Let ***Id*** be an instance of ***LhsId***.

Let ***X*** be an instance of ***ComputableExpr*** or ***Accessor***.

Assign (Id, X)

Requires: ***IsEqual (GetDesc (Id), GetD sc (X))***

}

__ADT for LhsId for an Elementary Variable__

S = {***LhsElementary***}

Ω = {

__Creators:__

CreateLhsElementary: ***Accessor ↪ LhsElementary***

__Modifiers:__

Assign: ***LhsId × ComputableExpr ↪ LhsId***

__Queries:__ None

}

__Axioms:__

{

Let ***a*** be an instance of ***Accessor***.

Let ***ce*** be an instance of ***ComputableExpr***.

Let ***le*** be an instance of ***LhsElementary***.

GetInnerTypeName (le) = VALUE

Assign (CreateLhsElementary (a), ce)

IMPLIES

(

(SetValue ((AccessVariable (a)), Evaluate (ce))); ***OR***

(SetValue (AccessLocation (a)), Evaluate (ce)))

)

GetDesc (CreateLhsElementary (a)) = GetDesc (a)

- The ***Descriptor*** is the same, not two ***Descriptors*** which are equal to each other. In short, this __Axiom__ cannot be satisfied by simply using two distinct ***Descriptors*** having the same properties.

GetAccess r (CreateLhsElementary (a)) = a

}

PreConditions:

{

Let ***a*** be an instance of ***Accessor***.

Let ***t*** be an instance of ***TypeName***.

Let ***ce*** be an instance of ***ComputableExpr***.

Let ***le*** be an instance of ***LhsElementary***.

CreateLhsElementary (a)

Requires: ***GetInnerTypeName (GetDesc (a))*** = BASICCOMPTYPE;

OR

GetInnerTypeName (GetDesc (a)) = POINTER

Assign (le, ce)

Requires:

IF ***GetInnerTypeName (GetDesc (le))*** = POINTER; ***AND***

GetInnerTypeName (ce) = POINTER

THEN

IsEqual (GetDesc (le), GetInnerTypeDesc (ce)) = T; OR

GetInnerTypeName (GetPointedToType (GetDesc (le)))

= VOID

ELSE

The ***InnerTypeName*** is BASICCOMPTYPE – and the **Precondition** is the same as that for ***SetValue*** of ***BasicVar,*** described above.

}

ADT for LhsId for Composite Variable

S = {***LhsComposite***}

Ω = {

Creators:

CreateLhsComposite: ***Accessor*** $\hookrightarrow$ ***LhsComposite***

Modifiers:

Assign: ***LhsId*** $\times$ ***Accessor*** $\hookrightarrow$ ***LhsId***

Queries: None

}

Axioms:

{

Let ***a, a1, a2*** be instances of ***Accessor***.

Let ***lc*** be an instance of ***LhsComposite***.

Assign (CreateLhsComposite (a1), a2) IMPLIES

(

SetEnvironment (AccessLocation (a1)) =

GetEnvironment(AccessLocation (a2))

)

GetDesc (CreateLhsComposite (a)) = GetDesc (a)

- The ***Descriptor*** is the same, not two ***Descriptors*** which are equal to each other.

GetAccessor (CreateLhsComposite (a)) = a

GetInnerTypeName (lc) = ENVIRONMENT

}

PreConditions:

{

Let ***t*** be an instance of ***TypeNam*** .

Let ***a*** be an instance of ***Accessor***

Let ***lc*** be an instance of ***LhsComposite.***

CreateLhsComposite (a)

Requires: ***GetInnerTypeName (GetDesc (a)) = t***

wherein, ***t*** ∈ **{ARRAY , RECORD}**

Assign (lc, a)

Requires: ***IsEqual (GetDesc (lc), GetDesc (a)) = T***

}

ADT for LhsId for a Function

S = {***LhsFunction***}

Ω= {

Creators:

CreateLhsFunction: Accessor ↪ LhsFunction

Modifiers:

Assign: ***LhsId × Accessor ↪ LhsId***

Queries: None

}

Axioms:

{

Let ***a*** be an instance of ***Accessor.***

Let ***f1, f2*** be instances of ***FunctionAccessor.***

Let ***lf*** be an instance of ***LhsFunction.***

Assign (CreateLhsFunction (f1), f2)

IMPLIES

(

(SetBlock (AccessVariable (f1)), AccessVariabl (f2))

OR

(SetBlock (AccessLocation (f1)),

GetBlock (AccessLocation (f2)))

)

GetDesc (CreateLhsFunction (a)) = GetDesc (a)

- The ***Descriptor*** is the same, not two ***Descriptors*** which are equal to each other.

GetAccessor (CreateLhsFunction (a)) = a

GetInnerTypeName (lf) = BLOCK

}

<u>PreConditions:</u>

{

Let ***a*** be an instance of ***Accessor***.

Let ***Lf*** be an instance of ***LhsFunction***.

CreateLhsFunction (a)

Requires: ***GetInnerTypeName (GetDesc (a)) =*** FUNCTION

Assign (Lf, a)

Requires: ***IsEqual (GetDesc (Lf), GetDesc (a)) = T***

}

<u>ADT for Command</u>

As previously noted, every programming language consists of States and Commands. Thus far the description of the present invention has focused on axiomatizing the State part

of programming languages, now the Command part of programming languages will be axiomatized.

The hierarchy of base ***C mmands*** is provided in Figure 14.

The particular view of a program depends on the type of programming language. For Functional Programming Languages, the program returns a ***Value*** that results from Evaluation of the ***Computable Expressions*** within it. A different view of a program as a State Transformer holds for Imperative Programming Languages wherein Evaluation of the program results in a State change, i.e., a change in ***Values*** of one or more ***Variables***. One of the semantics of a program (either Functional or Imperative) is its Evaluation. Evaluation of a program, as defined above, is compositional, i.e., it may be defined recursively as the resultant Evaluation of the constituents of the program. For example, consider the following statements:

LoopWhile

Its evaluation is the resultant evaluation of its constituent ***Commands***.

If-Else

Its evaluation is the resultant evaluation of its constituent ***Commands***.

Computable Expression

Its evaluation is the resultant evaluation of its constituent ***Computable Expressions***.

Only the ***Assignment Command*** causes a ***State*** change (in an Imperative Programming Language), whereas ***ComputableExpr*** always Evaluates to a ***Value*** in Functional as well as Imperative Programming Languages.

Command is the evaluation of a ***ComputableExpr*** that may be followed by a change of ***State***. The following is a listing of exemplary ***Commands***:

- ***Assignment, Branch*** (***Jump*** or ***Goto***), ***Loop, Skip, Alternator***.

- ***ExceptionHandler*** and ***ThrowExc ption*** are ***Commands*** used for Exception Handling.

- Every ***Computabl Expression*** is a ***Command***, including ***FunctionCall***.

- Every ***Block*** (which is a collection of one or more ***Commands***) is a ***Command***.

A ***Procedure-Call*** is the same as a ***Function-Call*** that returns ***Void***. Hence, ***Procedure-Call*** is considered merely a subset of ***Function-Call*** and thus there is no separate <u>Creator</u> is provided for ***Procedure-Call***. ***Function-Call***, in turn, is handled through ***Computable Expression*** (which is part of some kind of ***Commands*** such as ***Assignment***). Hence, there is no separate <u>Creator</u> for ***Function-Call***.

The properties specified for the base ***Command*** are set forth in the following algebraic specification:

S = {***Assignment, Branch, Alternator, LoopWhile, LoopFor, ComputableExpr, Skip, Block, Comment, ThrowException, ExceptionHandler***}

Ω = {

<u>**Creators:**</u> None

- Each individual kind of ***Command*** has its own <u>Creators</u>.

<u>**Modifiers:**</u>

SetLabel: ***Command × String ↪ Command***

- ***Label*** is not mandatory for ***Command***. Hence, this "***SetLabel***" is used to associate a ***Label*** with a ***Command***.

SetAddedToBlock: ***Command → Command***

<u>**Queries:**</u>

GetLabel: ***Command → String***

Print: ***C mmand → String*** (Prints ***SValue***)

Evaluate: ***Command × State → State***

IsAddedToBl ck: ***Command → Bool***

Individual Creators for different kinds of Command:

Since only the <u>Creator</u> functions differ for each individual kind of ***Command***, for convenience the <u>Creator</u> functions are listed here instead of in their own separate ADTs. The only exception being the ***Block Command***, which is described separately in its own ADT further below.

CreateAssignment : LhsId $\times$ ***Rhs*** ↪ ***Assignment***

wherein, ***Rhs*** is either a ***ComputableExpr*** or an ***Accessor.***

CreateBranch: ***String → Branch***

- The ***String*** parameter is the ***Label*** of another ***Command*** to which the ***Branch*** should take place.

CreateAlternator : ***List [BooleanExpr, Command] → Alternator***

- The ***List*** is a standard list of a tuples of ***[BooleanExpr, Command]*** and hence is not axiomatized any further.

- An ***If-Else*** is a specialized version of ***Alternator*** having a ***List*** of 2 tuples.
  - The 1^{st} tuple represents the ***If*** part;
  - The 2^{nd} tuple represents the ***Else*** part. The ***BooleanExpr*** of this tuple is the negation of the 1^{st} ***BooleanExpr*** (of the first tuple).

- A ***Switch-Case*** is also a specialized version of ***Alternator*** -- where the ***BooleanExpr*** for each ***Case*** is a ***BooleanExpr*** with the ***Integer Value*** for the ***Case*** in it, and the ***Default*** is a negation of the disjunction of all the preceding ***BooleanExpr.***

CreateLoopWhile : ***BooleanExpr*** $\times$ ***Command → Loop***

CreateL opFor : ***Bool anExpr*** $\times$ ***C mmand*** $\times$
L opVar $\times$ ***Step*** $\rightarrow$ ***Loop***

- ***LoopVar*** is a ***Variable*** of ***Int***, and ***Step*** is a non-zero ***Constant*** of ***Int***. In ***Lo pFor***, ***BooleanExpr*** should have ***L opVar*** as one of its constituents.

CreateSkip : ϕ $\rightarrow$ ***Skip***

CreateComment: ***String*** $\rightarrow$ ***Comment***

CreateThrowException: ***X*** $\rightarrow$ ***ThrowException***

wherein, ***X*** here is either an ***Accessor*** or an ***Expression***.

CreateExceptionHandler: ***Block*** $\times$ ***Block*** $\times$ ***List [String, Desc, Block]***
$\rightarrow$ ***ExceptionHandler***

- wherein, the first ***Block*** is the ***Try Block***, the second ***Block*** is the ***Clean Up Block*** and the list is a standard list of ***handlers***, wherein each ***handler*** contains the following:
  - a ***String*** (possibly empty), which is the name of the placeholder holding the Exception Object to be handled by the ***handler Block***;
  - a ***Descriptor*** stating the type for which the handler ***Block*** has to be executed; and
  - the ***handler Block*** to be executed.

}

<u>Axioms:</u>

{

Let ***c*** be an instance of ***Command***.

Let ***s*** be an instance of ***String***.

Let ***t*** be a ***TypeName***.

GetLabel (S tLabel (c, s)) = s

GetTypeName (c) = COMMAND

GetInnerTypeName (c) = t

where **t** ∈ {`BRANCH, SKIP, BLOCK, ASSIGNMENT, LOOP-FOR, LOOP-WHILE, ALTERNATOR, COMMENT, COMPUTABLE_EXPR, THROW_EXCEPTION, EXCEPTION_HANDLER`}

- The <u>Creators</u> for each individual kind of ***Command*** sets up the appropriate ***InnerTypeName.***

IsAddedToBlock (SetAddedToBlock (c)) = T

IsAddedToBlock (CreateX()) = F

- wherein, ***CreateX*** stands for the <u>Creators</u> for each individual kind of ***Command.***

}

<u>Preconditions:</u>

{

Let ***k*** be an instance of ***LhsId.***

Let ***c*** be an instance of ***ComputableExpr*** or ***Accessor.***

Let ***f*** be an instance of ***FunctionAccessor.***

Let ***z*** be an instance of ***Command*** and ***s*** be an instance of ***String.***

Let ***e*** be the ***Environment*** where the ***Label*** is to be set.

CreateAssignment (k, c)

Requires:

IsEqual (GetDesc (k), GetDesc (c)) = T;

OR

[GetInnerTypeName ((GetDesc (k))) = `BASICCOMPTYPE`***;***

AND

GetCompTypeName (GetDesc (k)) = `VOID`***;***

AND

GetInnerTypeName (GetDesc (c)) = `POINTER`***];***

OR

[GetInnerTypeName ((GetDesc (k))) = POINTER ;

AND

GetCompTypeName (GetPointedToTyp Desc (GetDesc (k))

= VOID ;

AND

GetInnerTypeName (GetDesc (c)) = POINTER]

SetLabel (z, s)

Requires: ***IsEmpty (s) = F ; AND***

IsAddedToBlock (z) = F

}

ADT for Block

A ***Block*** is represented as a "***D in C***" wherein, the ***D*** (***Declarations***) part of the ***Block*** is the ***Environment*** and the ***C*** (***Commands***) part of the ***Block*** is the ***Command*** (***Statement***) List. On creation, a ***Block*** has an empty ***Command*** List as well as an empty ***Environment***. Creation of ***Block*** is done either in the parser (when an ***unnamed Block*** is required as a ***Command***), or from within ***CreateFunction***.

S = {***Block***}

Ω = {

Creators:

CreateBlock: $\phi \rightarrow$ ***Block***

Modifiers:

AddCommand: ***Block*** $\times$ ***Command*** $\hookrightarrow$ ***Block***

SetAsConstant: ***Block*** $\rightarrow$ ***Block***

- This is applicable to ***Blocks*** within ***Functions*** and is ***SetAsConstant*** whenever the ***Function*** is ***SetAsConstant***.

Queries:

IsEmpty: ***Block → Bool***

HasCommands: ***Bl ck → Bool***

IsConstant: ***Block → Bool***

Evaluate: ***Block × State ↪ State***

Print: ***Block → String*** (Prints ***SValue***)

GetEnvironment: ***Block → Environment***

IsStatementLabelPresent: ***Block × String ↪ Bool***

}

<u>Axioms:</u>

{

Let ***b*** be an instance of ***Block***.

IsEmpty (b) This <u>Axiom</u> is the equivalent of the following conditions being satisfied:

(

Not (HasCommands (b); ***AND***

IsEmpty (GetEnvironment (b))

)

IsEmpty (CreateBlock ()) = T

HasCommands (AddCommand (b)) = T

IsConstant (CreateBlock ()) = F

IsConstant (SetAsConstant (b)) = T

IsAddedToBlock (CreateBlock ()) = F

}

<u>PreConditions:</u>

{

Let ***b*** be an instance of ***Block***.

Let ***c*** be an instance of ***Assignment***.

AddCommand (b, c)

Requires: ***IsConstant (b) = F ; AND***
IsComplete (b) = F; AND
(IsEmpty (GetLabel(c)) OR
IsStatementLabelPresent (b, GetLabel(c)) = F)

- A ***Constant Block*** (which is part of ***Constant Function***) cannot contain an ***Assignment*** since ***Assignment*** is the only ***Command*** that changes ***State*** and thus would violate the condition of constancy.

}

<u>ADT for GOTO (Branch)</u>

A ***GOTO*** (***Branch***) requires a ***Label*** to branch to. However, when a ***GOTO*** is encountered, the corresponding ***Label*** need not have been encountered or declared (e.g., if the ***Label*** is in the text subsequent to the occurrence of the ***GOTO***). In anticipation of such cases, ***Block*** needs to maintain a list of undeclared ***Labels***. As and when a ***Label*** declaration is encountered, ***Block*** will take that ***Label*** off the list of undeclared ***Labels***.

Hence, the following enhancements of properties for ***GOTO*** must be added in addition to those found in the ADT for ***Block*** (as specified above):

<u>Modifiers:</u>

AddUndeclaredTargetLabel:	***Block*** $\times$ ***String*** $\rightarrow$ ***Block***
DeleteUndeclaredTargetLabel:	***Block*** $\times$ ***String*** $\rightarrow$ ***Block***
SetAsComplete:	***Block*** $\rightarrow$ ***Block***

<u>Queries:</u>

HasUndeclaredTarg tLabel: ***Block → Bo l***

IsComplete: ***Block → Bool***

Axioms:

Let ***b*** be an instance of ***Block***.

Let ***s*** be an instance of ***String*** (indicating ***Label***).

HasUndeclaredTargetLabel (AddUndeclaredTargetLabel (b, s)) = T

IsComplete (CreateBlock ()) = F

IsComplete (SetAsComplete (b)) = T

Preconditions:

Let ***b*** be an instance of ***Block***.

Let ***c*** be an instance of ***Command***.

Evaluate (or execute) for ***Block*** cannot be performed if there is anything undeclared in ***Block***. Hence we specify the following **Preconditions**:

Evaluate (b)

Requires: ***HasUndeclaredTargetLabel (b) = F; AND***

IsComplete (b) = T

AddCommand (b, c)

Requires: ***IsComplete (b) = F***

ADT for Function

Function is representative of a named ***Block***. The creation of a ***Function*** also requires a ***Descriptor***, like that for ***Variable***. This ***Descriptor*** has the specifications for the ***Types*** of ***Arguments*** to the ***Function***, and its return ***Type***.

S = { ***Function*** }

Ω = {

Creators:

CreateFunction: ***FunctionDesc × String → Functi n***

- Construction of ***Functi n*** consists of ***Type-Name*** binding, followed by giving it a ***Bl ck***, but this is not explicit in the **Creator**. The ***Block*** will not be empty as it contains the ***Self Variable*** of the ***Function*** and the ***Parameters*** of the ***Function***. However, since the ***Function*** body is not yet in place, the **Query** ***IsDefined*** returns ***FALSE*** at this point.

- ***Location*** for a ***Function*** is given by its parent ***Environment*** at the time of creation, but this is not explicit in the **Creator**.

Modifiers:

SetBlock: ***Function × Function ↬ Function***

- ***SetBlock*** is provided for the purposes of method update. The ***Block*** of the 2^{nd} ***Function*** is copied, thereby overwriting the existing ***Block*** of the 1^{st} ***Function***.
- ***Function*** is also a kind of ***Variable***; hence, its ADT inherits all the **Modifiers** and **Queries** of base ***Variable.***

Queries:

IsDefined: ***Function → Bool***

Print: ***Function → String*** (Prints ***SValue***)

Evaluate: ***Function ↬ Value*** (Evaluates ***RValue***)

GetLocation: ***Function → Location***

GetEnvironment: ***Function → Environment***

GetBlock: ***Function → Block***

GetTypeName: ***Function → TypeName***

GetInnerTypeNam : ***Function → TypeName***

GetNam : ***Function → String***

GetDesc: ***Function → FunctionDesc***

}

Axioms:

{

Let ***s*** be an instance of ***String***, which names the ***Function***.

Let ***d*** be an instance of ***Descriptor*** for ***Function***.

Let ***f, f1, f2*** be instances of ***Function***.

GetTypeName (f) = VARIABLE

GetInnerTypeName (f) = FUNCTION

GetInnerTypeName (GetLocation (z)) = BLOCK

GetDesc (CreateFunction (d, s)) = d

IsDefined (f) = IsComplete (GetBlock (f))

GetEnvironment (f) = GetEnvironment (GetBlock (f))

GetEnvironment (f) = GetEnvironment (GetBlock (GetLocation (f)))

GetBlock (f) = GetBlock (GetLocation (f))

SetBlock (f1, f2) = SetBlock (GetLocation (f1), GetBlock (f2))

IsConstant (CreateFunction (s, d)) = F

IsConstant (SetAsConstant (f)) = T

- A ***Constant Function*** cannot contain an ***Assignment***. ***Commands*** are added to ***Function*** via ***Block***. So, when ***SetAsConstant*** is invoked on ***Function***, it is also invoked on the ***Block*** for the ***Function***, resulting in the following **Axiom**:

EqualBool (IsConstant (GetBlock (f)), IsConstant (f)) = T

}

Preconditions:

{

Let ***s*** be an instance of ***String***, which names the ***Function***.

Let ***d*** be an instance of ***Descript r*** for ***Functi n***.

Let ***f***, ***f1***, ***f2*** be instances of ***Function***.

Let ***e*** be an instance of ***Environment*** in which the ***Functi n*** is to be created.

CreateFunction (d, s)

Requires: ***IsEmpty (s) = F ; AND***

IsNamePresent (e, s) = F

SetBlock (f1, f2)

Requires:

IsConstant (f1) = F; AND

IsEqual (GetDesc (f1), GetDesc (f2)) = T

Evaluate (f1)

Requires:

GetInnerTypeName (GetReturnTypeDesc (GetDesc (f1)))

= BASICCOMPTYPE ;

OR

GetInnerTypeName (GetReturnTypeDesc (GetDesc (f1)))

= POINTER

}

ADT for Environment

Programs in a Programming Language are defined and executed in the context of an ***Environment***. This ***Environment*** has the knowledge of the ***Types*** supported by the Programming Language and its Typing Rules. The ***Environment*** is the substrate ***Type*** on which a Programming Language is defined, constructed, and executed.

The ***Environment*** consists of:

- Language Context – which is the knowledge of the ***Types*** supported by the Language and the Typing Rules. This defines the language.

  Program State – which is the set of ***Variables*** (and their ***Values***) declared for a given program. An execution of a Program is a function from **State** to **State**.

For ease of manageability, the ADT for ***Environment*** is partitioned into its separate interfaces (wherever appropriate) for achieving a set of related objectives. The ***Environment*** is the container for all ***Types***. Hence, the **Creators** for all ***Types*** (as mentioned in their respective ADTs) are actually targeted on the ***Environment***. In other words, each of these **Creators** has ***Environment*** as an ***Argument*** (which has not been mentioned explicitly in the ADTs). Hence, the **Creators** in this section are only repeated explicitly when necessary for clarity.

S = {***Environment***}

Ω = {

Creators:

CreateEnvironment: $\phi \rightarrow$ ***Environment***

Queries:

IsEmpty: ***Environment*** $\rightarrow$ ***Bool***

- ***Environment*** is empty if it does not have any ***Type*** instantiated in the form of ***Variable/Function*** declarations. However, the ***Environment*** does have knowledge of ***Types***.

Print: ***Environment*** $\rightarrow$ ***String***

Axioms:

Let **e** be an instance of ***Environment***.

GetTypeNam (e) = **ENVIRONMENT**

***GetInnerTypeNam (e)* = ENVIRONMENT**

IsEmpty (CreateEnvironment ()) = T

- The <u>**Axiom**</u> ***IsEmpty*** returns ***FALSE*** once anything is created in it through any of the <u>**Creators**</u> for any ***Type***.

<u>**Chaining of Environments & Scope Rules**</u>

The ***Environment*** is responsible for creating other ***Environments*** that are internal to it. Such chaining of ***Environments*** occurs at the time of creating ***Variables*** of ***Record/Array***, and ***Functions*** and ***Blocks***. Whenever an ***Environment*** creates an inner ***Environment***, it passes itself as the parent for the inner ***Environment***. This chaining is required for defining scope rules.

Any ***Get*** query on ***Environment*** begins from the current ***Environment*** and expands its search by going upwards to its parent (and continuing upwards to the outermost ***Environment***) until such time the ***Get*** succeeds or fails (as is the case where there are no more ***Environments*** available for search).

<u>**Modifiers:**</u>

CreateInnerEnvironment: ***Environment → Environment***

- A new ***Environment*** is created and the input ***Environment*** is updated to reflect the creation and chaining.

SetParentEnvironment: ***Environment × Environment***
→ Environment

wherein, the 2nd ***Environment*** is the Parent.

- This is required just in case the Parent needs to be changed to reflect dynamically changing scope rules (such as that for the ***Environment*** of a Class in any Object-Oriented programming language).

AddModul : ***Environment × String → Environment***

- A new Module ***Environm nt*** is created and the input ***Environment*** is updated to reflect the creation and chaining. The Module ***Environment*** is

contained in the input ***Environment***, and is referred to by the name given by the second ***String*** parameter.

<u>Queries:</u>

HasParentEnvironment:	***Environment*** $\rightarrow$ ***Bool***
GetParentEnvironment:	***Environment*** $\hookrightarrow$ ***Environment***
HasModule:	***Environment*** $\times$ ***String*** $\rightarrow$ ***Bool***
GetModule:	***Environment*** $\times$ ***String*** $\hookrightarrow$ ***Environment***

<u>Axioms:</u>

Let ***e1***, ***e2*** be instances of ***Environment***.

GetParentEnvironment (CreateInnerEnvironment (e1)) = e1
GetParentEnvironment (SetParentEnvironment (e1, e2)) = e2

<u>Preconditions:</u>

Let ***e*** be an instance of ***Environment***.
Let ***s*** be an instance of ***String.***

GetParentEnvironment (e)

Requires: ***HasParentEnvironment (e) = T***

GetModule (e, s)

Requires: ***HasModule (e, s) = T***

<u>Generic Queries and Preconditions</u>

<u>Queries on Name, Variable and Location</u>

IsVariablePres nt: ***Environment*** $\times$ ***String*** $\rightarrow$ ***Bool***

IsFunctionPresent: ***Environment*** $\times$ ***String*** → ***Bool***

IsC nstantPresent: ***Environment*** $\times$ ***String*** → ***Bool***

IsValidLocation: ***Environment*** $\times$ ***ValueAddress*** → ***Location***

GetVariable: ***Environment*** $\times$ ***String*** ↪ ***Variable***

GetFunction: ***Environment*** $\times$ ***String*** ↪ ***Function***

GetConstant: ***Environment*** $\times$ ***String*** ↪ ***Constant***

GetLocationForAddress: ***Environment*** $\times$ ***ValueAddress*** ↪ ***Location***

- ***Environment*** assigns an ***Address*** to every ***Location*** and allocates it to ***Variable***. ***Environment*** therefore has a map of ***Address*** to ***Location***, and one can get to any ***Location*** from an ***Address*** by querying ***Environment*** (this is done in case of ***Pointer***, where there may not be a ***Variable***).

<u>**Queries on Descriptor**</u>

IsXXXDescPresent: ***Environment*** $\times$ ***String*** → ***Bool***

where ***XXX*** = ***BasicCompTypeDesc*** or ***Array*** or ***Record*** or ***Pointer*** or ***Function.***

IsDescPresent: ***Environment*** $\times$ ***String*** → ***Bool***

GetBasicCompTypeDesc: ***Environment*** $\times$ ***String*** → ***BasicCompTypeDesc***

GetPointerDesc: ***Environment*** $\times$ ***String*** → ***PointerDesc***

GetArrayDesc: ***Environment*** $\times$ ***String*** → ***ArrayDesc***

GetRecordDesc: ***Environment*** $\times$ ***String*** → ***RecordDesc***

GetFunctionDesc: ***Environment*** $\times$ ***String*** → ***FunctionDesc***

GetDesc: ***Environment*** $\times$ ***String*** → ***Desc***

IsNamePresent: ***Environment × String → Bool***

- The query ***IsNamePresent*** is the ***L gical OR*** of the following four queries: ***IsVariablePresent, IsFunctionPresent, IsConstantPresent, IsDescriptorPresent.***

IsAccessible: ***Environment × String ↪ Bool***

IsPrivate: ***Environment × String ↪ Bool***

- Every ***Variable*** contained in the ***Environment*** is present with a ***Status***, whether it is ***Private*** or ***Public***. ***IsPrivate*** returns this status of the ***Variable***. ***IsAccessible*** returns true in the following cases:
    - The ***Variable*** is present in the ***Environment*** or in one of its Parents (up the ***Environment*** chain); or
    - The ***Variable*** is present in one of the ***Module Environments*** contained in the ***Environment***, and is not private in that ***Module***.

Axioms:

If a ***Location*** with ***ValueAddress*** has been allocated to a ***Variable***, then the ***Location*** returned by querying the ***Variable***, and the one returned by querying the ***Environment*** for that ***Variable*** are the same. This is reflected in the following:

Let ***v*** be an instance of ***Variable***.

GetLocation (v) = GetLocationForAddress (e, GetAddress (v))

Preconditions:

Let ***e*** be an instance of ***Environment***.
Let ***d*** be an instance of ***Desc***.
Let ***b*** be an instance of ***BasicTypeDesc***.
Let ***p*** be an instance of ***PointerDesc***.

Let ***a*** be an instance of ***ArrayDesc***.

Let **r** be an instance of ***Rec rdDesc***.

Let ***f*** be an instance of ***FunctionDesc***.

Let ***s*** be an instance of ***String***.

Let ***v*** be an instance of ***Value***.

Let ***va*** be an instance of ***ValueAddress***.

GetVariable (e, s)

Requires: ***IsVariablePresent (e, s) = T***

GetFunction (e, s)

Requires: ***IsFunctionPresent (e, s) = T***

GetConstant (e, s)

Requires: ***IsConstantPresent (e, s) = T***

GetXXXDesc (e, s)

Requires: ***IsXXXDescPresent (e, s) = T***

where ***XXX*** = ***BasicCompTypeDesc*** or ***Array*** or ***Record*** or ***Pointer*** or ***Function.***

GetDesc (e, s)

Requires: ***IsDescPresent (e, s) = T***

GetLocationForAddress (e, va)

Requires: ***IsValidLocation (e, va) = T***

IsAccessible (e, s)

IsPrivate (e, s)

The previous two <u>**Preconditions**</u> require: ***IsVariablePresent (, s) = T***

Simulating Modules

Modifiers:

MergeEnvironment: ***Environment*** $\times$ ***Environment*** $\times$ ***String*** $\rightarrow$ ***Environment***

- This Modifier is for simulating ***Modules***. The elements of 2nd ***Environment*** (belonging to the ***Module***) are merged into the 1st ***Environment***. The ***String*** represents ***Name*** of the ***Module*** and it cannot be empty.
- In the case in which the ***Names*** of one or more elements clash in the two ***Environments,*** then the names are differentiated by appending to them the ***Name*** of the ***Module.*** This ensures uniqueness of ***Names***. The uniqueness of ***Names*** in the 1st ***Environment*** is checked by corresponding queries for ***Name*** in ***Environment.***

Thus, each kind of ***Type*** and their respective properties has been specified by an appropriate ADT above. Having described the Classes for each ***Type*** in the Generic Typed DGC Classes Framework in accordance with the present invention some exemplary applications of this framework will now be addressed. The present inventive Generic Typed DGC Classes Framework is suitable for a wide variety of language tools such as, but not limited to, high-level programming language translation, compilation or static analysis.

Language Conversion

Because of the independence of the Generic Typed DGC Classes Framework to syntax of any programming language, it is particularly well suited for high-level language translation of a source high-level language computer program to an equivalent computer program in a target high-level language different from that of the source language. Alternatively, as discussed in detail further below, the present inventive framework may be used as a compiler when the target language is a low level language.

Figure 15 is an exemplary schematic diagram of language conversion (e.g., language translation and/or compilation) using the present inventive Generic Typed DGC Classes Framework. At the front end, a parsing interface 1510 parses a source program 1500

written in a particular source language. The parsing interface 1510 is language specific, thus, a different interface will be necessary for each source language. The corresponding classes are instantiated from the Generic Typed DGC Classes Framework 1520 thereby creating a semantic representation of the source program in memory. This activity is performed in the Semantic Actions of the parser. Thus, all syntax is stripped from the source program – however, the semantics of the source program is entirely captured by the Generic Typed DGC Classes Framework.

For example, in a Source Program written in Pascal when the parsing interface comes across the ***Variable*** Declaration:

```
Var a : Array [5] of integer;
```

The Generic Typed DGC Classes Framework instantiates the Class ***ArrayVariable*** that is added to the already instantiated Class ***Environment***. Similarly, for the ***Assignment*** Statement of a Source Program written in Pascal as:

```
a[2] := 20;
```

The Generic Typed DGC Classes Framework instantiates the Class ***Assignment*** that is added to the already instantiated Class ***Block***.

On the other end, a printer interface 1530 is plugged in to receive the semantic representation produced by the Generic Typed DGC Classes Framework 1520 that is combined with the syntax of the Target Language. The combination produces code in the Target Language 1540. The Printer Interface is language specific, thus a different printer interface will be plugged in for each Target Language.

For instance, the above ***Variable*** Declaration (which is now in memory in the form of the object of the Class ***ArrayVariable*** is printed in the Target Language C as:

```
int a[5];
```

While the object of the Class ***Assignment*** is printed in the Target Language C as:

```
a[1] = 20;
```

It is to be noted in the example provided above that the indexing of the second array element has been changed. Array indexing in Pascal starts from "1" whereas indexing in C

begins from "0". Accordingly, the second array element in Pascal is represented by "a[2]", but in C is represented as "a[1]".

These same principles may be adapted for conversion of an entire program module. By way of example, language conversion using the Generic Typed DGC Classes Framework will now be described for an example source program module referred to as "`Unit4.PAS`", written in the Delphi programming language and converted to its corresponding C++ code.

The example **`Unit4.PAS`** Source Program module (in Delphi programming language) is reproduced below with line numbers provided for convenience:

```
1    unit unit4;
2    interface
3    const
4    unit4_IntConst = 100;
5    type
6    unit4_Int = integer;
7    (* Pointer to integer *)
8    unit4_IntPtr = ^unit4_Int;
9    var
10   unit4_IntVar1,unit4_IntVar2 : unit4_Int =
     unit4_IntConst;
11   unit4_IntPtrVar : unit4_IntPtr;
12   procedure unit4_AddProc(var a : unit4_IntPtr);
13   function unit4_Mult(var unit4_IntVar1 : unit4_Int;
             const unit4_IntVar2 : unit4_IntPtr) :
             unit4_Int;
14   implementation
15   procedure unit4_AddProc(var a : unit4_IntPtr);
16   var
17   Local_Var : unit4_Int;
18   { Function within a procedure }
19   function unit4_Add(in a, b: integer): integer;
```

```
20        begin
21        unit4_Add := a + b;
22        end;
23        begin
24        Local_Var:= unit4_Add(unit4_IntVar1,
          unit4_IntVar2);
25        a^ := Local_Var;
26        end;
27        function unit4_Mult(var unit4_IntVar1 : unit4_Int;
                  const unit4_IntVar2 : unit4_IntPtr) :
                  unit4_Int;
28        begin
29        unit4_Mult := unit4_IntVar1 * (unit4_IntVar2^);
30        end;
31        end.
```

Following the conversion process shown in Figure 15, initially the source language (Delphi) is parsed using a parsing interface that is plugged into the front end and the semantics are capture by instantiating Classes from the Generic Typed DGC Classes Framework. The actions taken by the parser for instantiating appropriate ADT-based Classes from the Generic Typed DGC Classes Framework is described for each line of the exemplary source program above and produces the following semantics representation.

<u>Line 1</u>:

The Parser instantiates a ***Block*** for `unit4`. This ***Block*** contains an empty ***Environment***, and an empty ***Command*** list.

<u>Line 2</u>:

Ignored by the parser (as the keyword `interface` denotes the beginning of the Interface Section).

<u>Line 3</u>:

Ignored by the parser (as the keyword **`const`** denotes the beginning of the Constant Section).

<u>Line 4</u>:

The parser instantiates a ***Constant*** with ***InnerTypeName Int*** for **`unit4_IntConst`**. This ***Constant*** has a ***ValueInt*** contained in it. This ***ValueInt*** object is given the ***Integer Value 100***. This ***Constant*** is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

<u>Line 5</u>:

Ignored by the parser (as the keyword **`type`** denotes the beginning of the Type Section).

<u>Line 6</u>:

The parser instantiates a ***BasicCompTypeDesc*** with ***InnerTypeName Int*** for the newly defined type **`unit4_Int`**. This ***Descriptor*** is named, and gets the name **`unit4_Int`**. It is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

<u>Line 7</u>:

Ignored for the purposes of this exemplary description (as it is a Comment, though there is a ***Command*** called ***Comment*** in the Generic Typed DGC Classes Framework).

<u>Line 8</u>:

The parser now instantiates a ***PointerDesc*** for the newly defined type **`unit4_IntPtr`**. This ***Descriptor*** is named, and gets the name **`unit4_IntPtr`**. Since this is a ***Descriptor*** of ***Type Pointer***, it is given a "***PointedToTypeDesc***" – i.e. the ***Descriptor*** of the ***Type*** pointed to by this ***Pointer***. In this case the "***PointedToType***" given is **`unit4_Int`**. This ***PointerDesc*** is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

<u>Line 9</u>:

Ignored by the parser (as the keyword **`var`** denotes the beginning of the Variable Section).

Line 10:

The parser now instantiates a ***BasicVariable*** for each of the ***Variables*** with the names **`unit4_IntVar1, unit4_IntVar2`** respectively. Both have as their ***Type Descriptor*** the ***Descriptor*** created in **Line 6** (i.e. **`unit4_Int`**), and both have their ***Values*** equated to the ***Value*** of the ***Constant*** defined in **Line 4**. These ***Variables*** are then added to the ***Environment*** of the ***Block*** for **`unit4`**.

Line 11:

The parser now instantiates a ***PointerVariable*** for the ***Variable*** with the name **`unit4_IntPtrVar`**. It has as its ***Type Descriptor*** the ***Descriptor*** created in Line 8. This ***Variable*** is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

Line 12:

The parser now instantiates a ***FunctionVariable*** for the ***Procedure*** with the name **`unit4_AddProc`**. This ***FunctionVariable*** has a list of ***Arguments***, and a return ***Type***. Since **`unit4_AddProc`** is a ***Procedure***, the return ***Type*** of this ***FunctionVariable*** is set to **`VOID`**. The ***Arguments*** of the ***FunctionVariable*** are set according to the list given in the function/procedure declaration. Therefore, for **`unit4_AddProc`**, the argument list contains one argument, which is a ***Variable*** of ***Type*** **`unit4_IntPtr`**. This ***FunctionVariable*** is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

Line 13:

The parser now instantiates another ***FunctionVariable*** for the ***Function*** with the name **`unit4_Mult`**. Its return ***Type*** is set to **`unit4_Int`**, and its list of arguments is set according to the list here (i.e., the first argument of name **`unit4_IntVar1`** and type **`unit4_Int`**, and the second argument of name **`unit4_IntVar2`** and type **`unit4_IntPtr`**). This ***FunctionVariable*** is then added to the ***Environment*** of the ***Block*** for **`unit4`**.

Line 14:

The keyword **implementation** denotes the beginning of the Implementation Section. Therefore, no further ***Variables/Types/C nstants*** are to be added to this ***Block***.

Line 15:

The parser now comes across the body or definition of the ***Procedure*** **unit4_AddProc**. This marks the beginning of the inner (local) ***Environment*** of this ***Procedure***.

In the building of the memory representation, there is an important change that happens at this point. So far, all ***Variables***, ***Type*** declarations, ***Constants*** etc. were being added to the environment of ***Block*** for **unit4**. However, now, with the start of the ***Function*** definition, the current ***Environment*** (which was thus far of the ***Block*** for **unit4**) now changes.

The ***FunctionVariable*** contains within it a ***Block*** to which the parser will add the code and the local ***Environment*** for that ***Function***. Therefore, the current ***Environment*** now becomes the ***Environment*** of the ***FunctionVariable***.

Line 16:

Ignored by the parser (as the keyword **var** denotes the beginning of the Variable Section).

Line 17:

The parser now instantiates a ***BasicVariable*** for the ***Variable*** with name **Local_Var**. It has as its ***Type Descriptor*** the ***Descriptor*** created for Line 6. This ***Variable*** is now added to the current ***Environment***, which is the ***Environment*** of the ***FunctionVariable*** **unit4_AddProc**.

Line 18:

Ignored for the purposes of this exemplary description (as it is a Comment, though there is a ***Command*** called ***Comment*** in the Generic Typed DGC Classes Framework).

Line 19:

Now the parser instantiates a ***FunctionVari ble*** for the ***Functi n*** with the name **unit4_Add**. Its return ***Type*** is set to ***Integer*** (which is available as a ***Basic Computable***

Type in the **Language Context**), and its list of arguments is set according to the list here (i.e., both arguments are of type ***integ r***, with names **`a`** and **`b`** respectively.). This ***FunctionVariable*** is then added to the ***Environment*** of the current ***Block*** (i.e., that of the ***FunctionVariable*** named **`unit4_AddProc`**).

<u>Line 20</u>:

The keyword **`begin`** is the beginning of the ***Commands*** section of a ***Block***.

Since the body or definition of the ***Function*** named **`unit4_Add`** starts immediately, the changing of the "current ***Environment***" happens here as described in the explanation of Line 15. The current ***Block*** & ***Environment*** are now the ***Block*** & ***Environment*** of the ***FunctionVariable*** named **`unit4_Add`**.

<u>Line 21</u>:

The parser now instantiates an ***Assignment Command*** for the ***Assignment*** statement **`unit4_Add := a + b`**.

The things that happen before this are:

- An ***LhsId*** (Left-hand-side identifier) is created for **`unit4_Add`**.
- An ***ArithmeticAddExpression*** is created for **`a + b`**.

These are the two inputs required in the construction of the ***Assignment***, which is now added to the ***Commands*** of the ***Block*** for **`unit4_Add`**.

<u>Line 22</u>:

The keyword **`end`** marks the ending of the ***Commands*** section of the current ***Block***.

Another important change happens here. The inner ***Block*** (of the ***Function*** named **`unit4_Add`**) has been completed. This ***Block*** is not the current ***Block*** anymore. The current ***Block*** now happens to be the ***Block*** of the ***Procedure*** named **`unit4_AddProc`**).

<u>Lines 23-26</u>:

The parser now constructs and instantiates (in a manner similar to that done earlier for Line 21) the two ***Assignm nts*** and adds them to the ***Commands*** section of the ***Bl ck*** for **`unit4_AddProc`**. The building of the memory representation like that explained earlier for Lines 19-22.

Lines 27-30:

The parser now comes across the body or definition of the ***Procedure*** named **`unit4_Mult`**. The building of the memory representation is similar to that explained earlier for Lines 19-22.

Line 31:

The keyword **`end`** marks the ending of the ***Commands*** section of the current ***Block***. Since this is the last (or the outermost) ***Block***, this is the end of the entire unit (i.e., end of **`unit4`**).

Figures 18 and 19 are exemplary schematics of the memory representations of the ***Blocks*** named **`unit4`** and **`unit4_AddProc`**, respectively, in the example provided above.

On the back end, a printing interface is plugged to generate **Code** in the Target Language, which in this example is C^{++}. The printing interface, performs the following:

1. Takes the Semantics produced by the Generic Typed DGC Classes Framework (i.e., from the Semantic representation created above.)
2. Combines the semantic representation with the Syntax of C^{++}; and
3. Generates Source Code Files for C^{++}.

For the above module "**`Unit4.PAS`**", the C++ Printing Interface generates the following two files in C++ viz: "**`unit4.h`**" and "**`unit4.cpp`**". The code for both these files is given here. The generated C++ code is semantically equivalent to that of the input Delphi code.

I – Code for unit4.h

```
typedef int unit4_int;
typedef unit4_int *unit4_intptr;
void unit4_addproc(unit4_intptr * a);
unit4_int unit4_mult(unit4_int * unit4_intvar1, unit4_intptr
                                unit4_intvar2);
const int unit4_intconst = 100;
unit4_int unit4_intvar1 = unit4_intconst;
unit4_int unit4_intvar2 = unit4_intconst;
unit4_intptr unit4_intptrvar;
```

<u>**II – Code for unit4.cpp**</u>

```
  #include "unit.h"

  void main()
  {
    {
    }
  }

  void unit4_addproc(unit4_intptr * a)
  {
    struct _DGC_unit4_addprocEnv runit4_addproc;
    runit4_addproc.a = a;
    int unit4_add(struct _DGC_unit4_addprocEnv&, int, int);
    runit4_addproc.local_var    =    unit4_add(runit4_addproc,
    unit4_intvar1, unit4_intvar2);
    (*(*(runit4_addproc.a))) = runit4_addproc.local_var;
  }

  int unit4_add(struct _DGC_unit4_addprocEnv
                      &DGC_unit4_addproc, int a, int b)
```

```
{
   int unit4_add;
   unit4_add = (a + b);
   return unit4_add;
}

unit4_int unit4_mult(unit4_int * unit4_intvar1,
        unit4_intptr unit4_intvar2)
{
   unit4_int unit4_mult;
   unit4_mult = ((*(unit4_intvar1)) * (*(unit4_intvar2)));
   return unit4_mult;
}
```

The printing interface starts with the outermost ***Block***. The ***Environment*** of the ***Block*** is printed first, and then its list of **Commands**. Each **construct** is printed recursively – till the basic **construct** is reached. Printing of the major **constructs** is explained below:

***Block*:**

For printing a ***Block*** (which may or may not belong to a Function) – the printing interface first prints the opening brace (as per the C++ syntax), then recursively asks the ***Environment*** and the ***Commands*** of the block to print themselves, and then prints the closing brace (again as per the C++ syntax).

Each of the ADTs of the Generic Typed DGC Classes Framework has the built-in capability of printing itself in a generic manner. For printing specific syntax of programming, these capabilities are enhanced with the syntactical elements of the specific languages (C++ in this example).

***Environment*:**

Printing of the ***Environment*** involves printing of the ***User Defined Typ s***, ***Constants*** and ***Variables***, in that order. Each ***User Defined Type*** is printed as per the C++ '**typedef**' syntax.

Variable:

Printing of a ***Variable*** involves printing of its ***Type***, followed by its ***Name***, and followed by its default ***Value*** (if any).

Assignment:

Printing of an ***Assignment*** involves printing of the ***LhsId*** (which is usually the ***Name*** of the ***Lhs Variable***), followed by the C++ ***assignment operator*** '**=**', followed by the printing of the ***Rhs Expression***.

As is evidenced by the example described above, the Generic Typed DGC Classes Framework in accordance with the present invention may be readily used for high level language translation. Use of the Generic Typed DGC Classes Framework in connection with high-level language translation is beneficial over conventional language converters in several respects. The language and syntax independence of the present inventive Generic Typed DGC Classes Framework eliminates all possibility of syntax-related conversion errors. Along these lines, since the Generic Typed DGC Classes Framework is based entirely on semantics, rather than syntax, the original computer program written in the source language and the translated computer program written in the target language will always be semantically equivalent. That is, the translated computer program written in the target language when executed in the same environment is guaranteed to produce the same results as those produced by the original computer program written in the source language.

Yet another benefit associated with using the present inventive Generic Typed DGC Classes Framework for high level language translation is that since different constructs in programming languages are nothing but compositions of the core concepts present in the intermediate Generic Typed DGC Classes Framework, even those features present in the Source Language yet not available in the Target Language can still be converted.

Several illustrative examples of application of the Generic Typed DGC Classes Framework for programming language conversion are discussed below:

1. ***<u>Conversion of nested functions from Pascal to C</u>***:

Pascal supports nested Functions (one function block within another), but C does not. The semantics behind nested Functions in Pascal is that the Environment of the outer Function is available to the inner Function. Generally, the nesting Function is broken down into its components, namely, capturing the Environment of the outer Function, and making this Environment available to the inner Function. This same functional result is realized in C by storing the Environment as a data structure, and passing the data structure as an additional parameter to the inner function. The converted inner function in C behaves exactly in the same manner as the original Pascal nesting function.

2. ***<u>Conversion of With-Do statement from Pascal to C</u>***:

Pascal has a construct "**`with<Variable> do <statements>`**" used for record type variables, wherein, "**`With`**" simply provides an abbreviated notation for referring the fields of a record or structure. C does not include this construct, but the same functionality may be realized. When converting a "**`with...do...`**" construct, all variable references in the statements occurring in the **`<statements>`** part are appended by the name of the record variable. The converted C code performs exactly in the same manner as the original Pascal statement.

In a similar exemplary application, the present inventive Generic Typed DGC Classes Framework may be used to develop the first phase of a compiler, i.e., to generate assembly or object code. Compilers can also be classified as Language Converters, albeit, conversion of a high-level language to a lower level machine language.

To build a retargetable compiler, based on the Generic Typed DGC Classes Framework, and which is independent of the particular programming language requires:

- a parser interface at one end; and
- a printing interface at the opposite end to print out the generated assembly or object code,

This uses the same system and method shown in Figure 15 and described above with respect to high-level language translation. The only difference being that instead of the Target Language being a high level program language in the case of Language Translation, when used as a compiler the Target Language is assembly or object code.

Both conventional compilers and those based on the Generic Typed DGC Classes Framework preserve semantics, however, only the Generic Typed DGC Classes Framework based compilers (in accordance with the present invention) provide semantics explicitly and compositionally.

Numerous advantages are provided by using the Generic Typed DGC Classes Framework based compiler instead of a conventional compiler. Heretofore, compilers typically used Composable Attribute Grammar (CAG) as a parsing technique. A CAG is represented as a composite of several smaller component Attribute Grammars (AGs), each designed to solve a particular sub-problem such as scope resolution, expression or evaluation. Thus, large problems are decomposed into smaller component sub-problems each handled by a component Attribute Grammar. In addition to the component Attribute Grammars (AGs), the CAG also consists of glue Attribute Grammar and an interface, which defines the correspondence between the glue and the component AGs. The glue AG is an AG with underlying context-free grammar specifying the phase-structure of the source language.

Each component AG is based on a simplified phrase-structure that reflects the properties of its sub-problem rather than the phrase-structure of the source language. This decomposition principle associated with component AGs is similar in nature to the core concepts or building blocks that form the very basis for the present inventive Generic Typed DGC Classes Framework. Instead of providing different component AGs it is simpler to add different interfaces for different Generic Typed DGC Classes Framework constructs in accordance with the present inventive framework. The present inventive Generic Typed DGC Classes Framework, being generic, can capture the semantics of any language. Hence, the use of CAGs is limited to defining the phase structure of the source language at hand, i.e., for writing the language specific parser.

Another advantage associated with the present inventive Generic Typed DGC Classes Framework based retargettable complier is that it has no language dependency or execution model dependency typical of intermediate code forms (e.g., Postfix Notation, Parse Trees (Abstract Syntax Trees), Three-Address codes (triplet/quadruple)) used in code generation with conventional compilers. Each of these conventional intermediate code forms has some form of language or execution model dependency. Postfix Notation is only suitable with functional languages in which the source program is mostly expressions. Parse

Trees are extremely dependent on the source language syntax. Three-Address codes are preferred in many optimizing compilers since it permits rearrangement of intermediate code in a convenient manner. However, every triplet/quadruple entry requires the storage of pointer to Symbol Table entries of the respective symbols involved in their formation. In addition, every triplet/quadruple entry increases the number of temporaries required for code evaluation. Accordingly, Three-Address codes are mostly suitable for registered-based machines.

The Generic Typed DGC Classes Framework based compiler in accordance with the present invention overcomes all these language and execution model restrictions in that it is universally suitable for use with any sequential programming language and completely syntax independent (or source language independent).

Furthermore, any imperative programming language can be represented using the present inventive Generic Typed DGC Classes Framework. Unlike the Three-Address codes that are suited for register based machines or chips, the present inventive Generic Typed DGC Classes Framework based compiler is retargetable in that it provides a generic representation of the source language and is independent of the target processor. Thus, the Generic Typed DGC Classes Framework can accommodate different interfaces to generate code for different machines and/or chips thereby being capable of compiling source code into machine code for different target processors using the same framework. The retargetable compiler is target independent and uses a description of the target architecture as input in order to generate code for a certain algorithm. Figure 16 is a schematic diagram of an exemplary Retargetable Compiler architecture based on the Generic Typed DGC Classes Framework in accordance with the present invention. In the example shown in Figure 16 three different Code Generation interfaces 1630a, 1630b, 1630c are provide, however, any number of interfaces can be implemented, as desired. Alternatively, as shown in Figure 17, the Generic Typed DGC Classes Framework representation of the Assembly Language 1720' may be derived from the Generic Typed DGC Classes Framework representation of the Source Language 1720. Once again different code generation interfaces may be implemented on the Generic Typed DGC Classes Framework representation of the Assembly Language. The configuration shown in Figure 17 is desirable in that the Generic Typed DGC Classes Framework of the Source Language is independent of and not burdened by the code generation interfaces 1730a, 1730b, 1730c.

Yet another advantage of the present inventive Generic Typed DGC Classes Framework based compiler over conventional compilers is with respect to code generation. Determining which machine code sequence is best for a given Three Address code construct may require extensive knowledge about the context in which that construct appears. Being compositional, every Generic Typed DGC Classes Framework construct has knowledge of the context required, whereas for Three Address code additional efforts are required to ascertain such information.

Still another advantage of using the Generic Typed DGC Classes Framework based compiler is that the compositional separateness eliminates the need for separate Symbol Tables for tracking all the symbol names used in the program and the essential information, associated with conventional compilers.

Interpreter

As previously discussed, a compiler translates the entire source program in advance to produce a separate file of executable machine code, which is then executed directly. In contrast, an interpreter is a computer program that executes the source code of another program by translating its statements one at a time into machine code instructions and executing them immediately. Interpreters are particularly useful in statically evaluating programs in the source language without a compiler. Since the Generic Typed DGC Classes Framework is language independent, a single universal Generic Typed DGC Classes Framework based interpreter can be used for any source language once the source language has been parsed and its semantics have been captured correctly into the Generic Typed DGC Classes Framework.

Static Analyzer

On a related note, the same Generic Typed DGC Classes Framework interpreter, when combined with the axiomatization of Execution Semantics based on Theory of Abstract Interpretation may serve as a Static Analyzer. A Static Program Analyzer (Abstract Interpreter) is a program written in a programming language (Meta Language, that is, a programming language used to manipulate logical proofs such as LISP or PROLOG) which receives as input the source code of a Source Program written in a programming language, analyzes the Source Program, and predicts the behavior of the Source Program

without executing it. A static analyzer based on the Generic Typed DGC Classes Framework requires a parser interface and an analysis interface. Thus, the Generic Typed DGC Classes Framework based static analyzer can be used to predict approximate run-time program properties without executing the program as well as being used as a criteria-based optimizer for compilers.

These are but a few illustrative examples of the use of the present inventive Generic Typed DGC Classes Framework in accordance with the present invention. The universality and decompositional nature of the inventive framework makes it ideal for a wide variety of applications beyond those mentioned by way of example herein. Furthermore, the present inventive framework has unlimited future use because the fundamental core constructs therein can be extended for use with all future programming constructs without compromising on any thing that has been developed and is offered with the Generic Typed DGC Classes Framework.

Thus, while there have been shown, described, and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the invention. For example, it is expressly intended that all combinations of those elements and/or steps which perform substantially the same function, in substantially the same way, to achieve the same results are within the scope of the invention. Substitutions of elements from one described embodiment to another are also fully intended and contemplated. It is also to be understood that the drawings are not necessarily drawn to scale, but that they are merely conceptual in nature. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

All of the references, publications and patents referred to herein are each incorporated by reference in their entirety. Any names or labels provided, for example, labels assigned to the different Types, are for illustrative purposes only and are not intended to limit the scope of the invention.